Ninth Annual Field Conference

ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS

MOOSE MOUNTAIN-DRUMHELLER

September 1959

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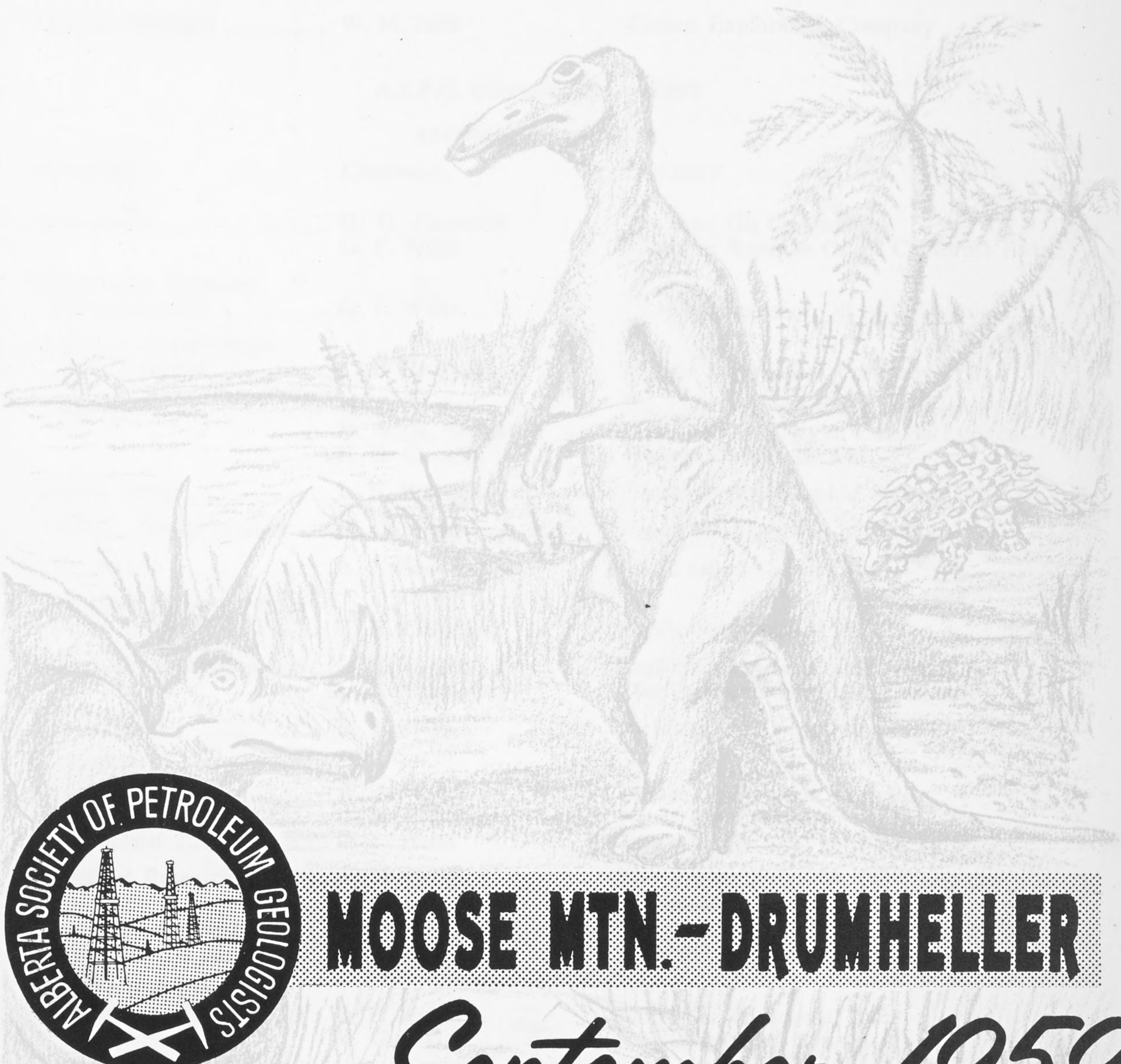
Ninth Annual Field Conference



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ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS

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H. W. Woodward

PREFACE

The Executive of the Ninth Annual Field Conference are pleased to present this book of technical papers and road logs of the Moose Mountain-Drumheller area.

The field trip localities were selected by the A.S.P.G. 1958 Executive, under advisement by past Field Conference organizers, to provide a Calgary based Conference. Field trips in the vicinity of Canada's Oil Capital are expected to provide a saving to delegates during a lean year for our Industry, and will permit us to examine the geology which crops out essentially in our own backyard.

In order to set the stage for the field excursions, surface papers in this book highlight the geology of the two widely separated outcrop areas at Moose Mountain and Drumheller; subsurface regional papers and producing field papers treat the geology of the intervening area.

The trip to Moose Mountain, a Palaeozoic inlier situated in the Foothills close to the Front Ranges of the Rocky Mountains, only 50 miles southwest of Calgary, gives us an opportunity to examine, at first hand, Mississippian rocks which provide the reservoirs for the major oil and gas fields under the Foothills and Plains of southwestern Alberta.

The trip to Drumheller, centre of a coal mining district about 90 miles northeast of Calgary, permits examination of Upper Cretaceous coal-bearing rocks exposed in deeply incised valleys — the Badlands of the Red Deer River Valley. Here on the dinosaur trail, abandoned coal mines located close to wells of the Drumheller and West Drumheller oil fields, illustrate graphically the trends of energy sources from coal to hydrocarbons and of exploration from surface to subsurface.

The papers included in this book adequately support the field excursions.

This year the format and arrangement of the Guide Book is changed somewhat from previous years. A type is used which allows more words per page. Illustrations have been arranged where possible to fit into the body of the text, and for the first time in recent years we have no 'fold-ins.' The road logs are printed in a small yet easy to read type which permits a more compact layout. Close integration of road logs and technical papers has been achieved through the joint use of maps and illustrations throughout the book. All this is in keeping with the accent on economy for this year's Conference.

We extend our thanks to the authors for their co-operation in meeting our deadline, and to the many companies and individuals who have contributed time, materials and technical services to this book.

It is our sincere wish that this Conference contributes to the understanding of the geology of the region and provides a stimulus for future work.

G. H. Austin

ALBERTA ENERGY SOURCES, COAL TO HYDROCARBONS; EXPLORATION, SURFACE AND SUBSURFACE

FLOYD K. BEACH [1]

INTRODUCTION

Through the ages of recorded history up to less than 200 years ago, man was dependent on the strength of his hands and back plus the use he could make of domestic animals, wind and water-wheel. In China today we find man moving dirt in baskets on his back, but we in North America would be lost without the energy sources provided by the steam engine, the gasoline and diesel engines and water power.

A century ago my grandfather plowed with a team of horses, carried a sack of seed wheat on his shoulder and broadcast the seed by hand. He cut the grain with a cradle by the strength of his arm, bound sheaves by hand and threshed the wheat with a flail. Water power in a village powered a grist mill to make flour and his children were cautioned to fill up on potatoes before eating bread, which had cost him so much to produce.

The same energy sources we enjoy today have been in existence over the ages. It is only in our ability to discover and utilize them that we gain advantages that our ancestors did not have.

Utilization is as important a factor as possession of energy sources, but possession of the sources is not at all evenly distributed and Alberta has within her boundaries just over half of Canadian coal reserves, and five-sixths of Canadian oil and gas reserves. Installed hydro-electric generating capacity is relatively small, a mere 1.6 percent of the Canadian total, but it is very useful and will expand to some extent with demand.

Atomic fuel looms as a future source of energy but present forecasts suggest that uranium is not likely to replace coal, oil and natural gas in parts of the world where they are easily accessible. Alberta has no known uranium that can be mined economically, although deposits at Great Bear Lake and Lake Athabasca are close.

Alberta has been handicapped geographically in utilizing energy sources for manufacturing. Every item we bring to the province costs more because of freight rates and everything we have to sell is less remunerative because of transmission costs. As population grows in the province the handicap lessens. In the meantime Albertans must be efficient in exploiting such natural advantages as they possess.

EARLY REPORTS OF COAL

Sir Alexander Mackenzie in 1789 reported fires burning in exposed coal seams in what is now the Northwest Territories. David Thompson, the greatest amateur geographer the world has known, spent the winter of 1787-88 beside the Bow River where Calgary now is, and in 1800 noted coal occurrences along the North Saskatchewan River above Rocky Mountain House. Sir George Simpson in 1841 reported coal at Edmonton. The Palliser expedition of 1857 to 1860 recorded the natural resources and geology of the Plains and up into the Rocky Mountains. J. B. Tyrrell, (1887) described the area around Rosebud River and Wintering Hills. Among other early writers on coal resources were G. M. Dawson, McConnell, Dowling and Cairnes.

COAL RESERVES

John A. Allan (1920) quoted an estimate by Dowling, placing Alberta coal reserves in seams one foot or more in thickness and less than 4,000 feet deep at 673 billion metric tons, plus probable reserves that brought the total to over a trillion tons. Dowling carried his figures to seven significant places and observing how lenticular coal seams are we wonder at the basis of his figures.

John Davis collected estimates for the Gordon Commission of mineable coal in seams three feet or more thick to a depth of 3,500 feet and his figures are only about 10 percent of Dowling's.

COAL MINING

Before settlement of land east and northeast of Calgary, a trail with multiple ruts ran toward the Rosebud River and I suspect most of those ruts were made by early ranchers hauling coal for their own use, obtained from outcrops.

The first recorded mining of coal in Alberta was in 1881 when a coal seam was opened at Lethbridge. Coal was hauled to Medicine Hat for Canadian Pacific Railway locomotives on rail-

1 Consultant, Calgary, Alberta.

way construction; and when it proved satisfactory, a narrow gauge line was built to Medicine Hat to supply the transcontinental railway. The mine at Anthracite was opened in 1882, started regular mining in 1888 and was shut down in 1904. Canmore was opened in 1883, started commercial production in 1891 and still operates. Bankhead mine operated 1905 to 1922. Without these mines, operation of the Canadian Pacific Railway as a transcontinental line would have been delayed.

The narrow gauge line from Medicine Hat to Lethbridge was widened to standard gauge and continued through the Crowsnest Pass in 1896, where mines were opened at Frank (date uncertain), Lille in 1901, Coleman and Bellevue in 1903.

Coal was first mined at Drumheller in 1911 and the railway afforded an outlet for it in 1912.

Mines at Nordegg and on the Coal Branch (south of Edson) were opened in 1913. Mining was discontinued at Nordegg in 1956 and at Mountain Park (on Coal Branch) in 1957.

Other Prospects

Harry A. Ford took up coal leases in the valley of the Highwood River and P. Burns took coal leases farther north on the south fork of Sheep River. Burns' leases were located by Julius Rickert, a genius from France, and he was kept on Burns' payroll for some years. Both the Ford and Burns leases saw some exploratory development but have never had commercial outlet. Some small mining was carried on west of Turner Valley and W. S. Herron, while hauling coal by wagon across Sheep River in 1910 noted and sampled the gas bubbling through the water, and this led to discovery of Turner Valley.

One promotional move to afford an outlet for some of the coal was made by John Breckenridge when around 1913 or 1914, he graded part of what was to be an electric railway, and traces of the grade can be seen from Anderson Road and near the junction of Highways 2 and 22, south of Midnapore.

Coal Mining Statistics

Provincial records indicate mining of 1,500 tons in 1881. By 1900 the annual production was less than 200,000 tons, but in 1920 it reached nearly 7 million tons with total coal mined to that date of over 60 million tons. Professor N. C. Pitcher in 1920 projected that by 1927 as much as 10 million tons might be mined annually if increases in population and markets in the province could be augmented by exports to the western United States. His forecast appeared reasonable at the time, but realization as shown by the records saw only 4.75 million tons mined in 1934, increasing to a maximum in 1946 of 8.83 million tons and dropping to 4.9 million tons in 1954 and a mere 2.5 million tons in 1958.

Such departures from reasonable forecasts make us pause before forecasting oil and gas production. The reasons for the drop in coal production are easy to see in retrospect. Increased use of natural gas for heating and a change-over in railway fuel, first to bunker oil in steam locomotives, then to diesel locomotives. A bright spot for coal in the near future will be mentioned in discussing water power.

Recovery Factor for Coal

In the 1919 report of the Alberta Mines Branch, J. T. Stirling stated that of 100.5 million tons affected by mining operations in 15 years, only 47.5 million tons were extracted and 26.6 million tons lost beyond hope of recovery. He termed this a deplorable fact that called for immediate consideration and investigation. Stirling carried his estimates to nine significant figures and I repeat only the first three or four and conclude that they indicated a possible 73 percent recovery factor. Alberta demand for domestic purposes was always seasonal, thus favoring room-and-pillar methods of mining and the figure of 73 percent appears to be high, if anything. John Davis remarks that sometimes 80 or 90 percent of the coal in a seam is recovered, but recovery may fall as low as 20 percent and he uses a consistent 50 percent recovery factor in his 1958 tabulation.

Hydro-Electric Power

The paper by Karl Mygdal in the A.S.P.G. 1956 Guide Book goes into some detail on the 11 power plants on Bow River and its tributaries. Since then the Cascade plant has been doubled in size, and work is in progress in the enlargements of Spray and Rundle plants.

Calgary Power Company has interconnection among hydro-electric plants and thermal plants at Edmonton, Lethbridge, Medicine Hat and Wabamun. All these thermal plants at present use natural gas fuel and operate best on base load. Fluctuations in demand are best met from hydro-elec-

tric, for one or several stations can be put on production by a distant operator on very short notice and shut down just as quickly. There are times of low water when thermal power is used to pump water back into a reservoir if minimum demand falls below the base load set at thermal stations, and Alberta fuel costs are the cheapest on the continent.

As demand increases the Wabamun plant will be enlarged and as the load reaches a certain figure it is planned to use coal from strip mines operated by the company close to the plant, with decrease in use of gas. The point where the change to coal will be made is expected to be when the coal requirement will reach about 750,000 tons a year and it is possible that coal consumption in this one plant may reach 1,500,000 tons a year or 60 percent of the amount of coal mined in Alberta in 1958.

Strip mining will be of no hope to underground miners, for it will be a mechanical operation of dirt moving and coal removal. A thermal plant at Crowsnest has been shut down for some years. It operated on coal mined below the surface and was the most costly unit in the province to operate.

Canadian Utilities has the only other system of power generation and distribution in the province. All its plants are thermal. A plant at Forestburg operates on coal from strip mines, purchased on contract. A plant at Drumheller still operates on coal; natural gas from casinghead nearby contains sulphur and unless purified is not considered safe for use in existing equipment. A plant at Vermilion operates on gas, as does a plant at Valleyview. Plants at Grande Prairie and Taylor are hooked up, but most of the load they did carry is being taken by Valleyview.

Between these two systems electricity is delivered not only to cities and towns, but also to a very extended rural demand and many farms are supplied with current.

Oil and Gas

The first gas discoveries in Alberta were made when drilling for water for locomotive use and when exploring for coal at Medicine Hat. The Medicine Hat discovery in 1890 was in a shallow pay zone and it was followed in 1904 by a discovery in the Medicine Hat sand and streets were lit by gas reasonably soon after.

Gas was held out as an incentive to attract industry, but cheap fuel alone did not achieve industrialization. Fuel does not normally dominate industrial manufacturing costs. Markets and the cost of shipping to markets form a major factor in successful manufacturing. Some ventures at Medicine Hat have succeeded because of cheap fuel but a number of other ventures failed.

Early wells were not cemented and transmission pipes were not protected against corrosion. Gas was at times more of a hazard than an asset.

The Bow Island field was discovered in 1909 and appears to have been located after geological surface studies by Eugene Coste. A few wells near the discovery proved a field underyling 6 or 7 square miles. No well was cored and few if any drilled deep enough to determine the sand thickness. About all that was known of the field was open flow and closed pressure. However, a 16-inch line some 175 miles long was laid in 1912 to supply Calgary with gas. When laid, it was the longest line of its size of which we can find record.

When the supply began to fail around 1920, efforts were made to find other gas fields close to the line, but with minor results. Foremost was the best discovery and it has been useful in meeting peak loads for the Lethbridge area.

Oil was found in Waterton Park in 1902 near a seepage but the quantity was not great enough to make the venture commercial.

The Turner Valley discovery of 1914 was based on a seepage of gas containing fractions heavier than methane. Termed an oil discovery at the time, it was actually condensate from the Mesozoic. The large flow of sour gas and condensate from the Palaeozoic, found in 1924, afforded a welcome addition to the Calgary gas supply and the condensate formed a good additive to motor gasoline. Liquid phase oil from the Palaeozoic was discovered in 1936, and Turner Valley became the first major oilfield in Alberta.

Other Oil Discoveries

We will not review discoveries of oil in the early years in detail, but in general oil pools on the Plains were small. Wainwright, Dina, Lloydminster and Vermilion were low gravity, black oils. Princess was the first Devonian discovery. All of these were largely based on surface geology or chance. Princess had much gas with small oil reserves. Taber and Conrad were small, medium

gravity oil fields, located on surface geological work with some shallow test-hole drilling.

During the period of these discoveries, drilling techniques improved. The cementing of casing reduced the hazard of wild wells. Rotary drilling replaced cable tools. At first operators felt cable tools were needed for exploration, but with the perfecting of drillstem testing, electric logging, coring and gun perforating, it became usual to drill exploratory wells with the rotary rig.

But for some years Turner Valley was our one major oil field and it was in the Disturbed belt. To the east of the Disturbed belt, the Plains presented what seemed to be an undisturbed homocline with no surface indication of more than minor undulations favorable to oil accummulation.

Allan and Sanderson in work done in 1925 but not published until 1945, remarked (p. 49) that "the structure sections shown . . . indicate broad undulations . . . (but) this does not mean that structure at depth would be favorable for the accumulation of petroleum or natural gas."

With the only major oil field in the Disturbed belt, a number of wells were drilled in it, based on surface geology, but the success ratio was alarmingly low and the wells costly.

Geophysical Work

Surface magnetometer surveys were tried without success. The gravity meter lacked any great resolution although recently it has proven useful in Ontario to detect pinnacle reefs at moderate depth. The first reflection seismic surveys, made in the Disturbed belt, could not be interpreted, but on the Plains they gave information. A refraction survey followed a gravity survey and led to the discovery of Pincher Creek field. Jumpingpound is also credited in part to seismic surveys and in part to surface and subsurface geology.

Stratigraphy and Seismic Surveys

The most constructive approach to oil finding, and incidentally a very costly one, came as Imperial Oil drilled what may be called a cross-section of the Plains with detailed studies of the stratigraphy. It started at Lethbridge, went east into Saskatchewan, then north and again westward. Each location was based on seismic surveys in order to choose favorable spots for oil accumulation. It was only when the cross-section had reached Leduc that the search was crowned with success. Since that discovery, other major fields have followed rapidly, and the end of discoveries is by no means in sight, for density of wildcat drilling is still very low in comparison with that of most of the United States.

Reservoir Engineering

Reservoir engineering has taken great strides, with techniques permitting accurate estimates of reserves in a field and formulas for production practises that will yield maximum recovery.

The law of capture has been curbed by general recognition that fair reservoir withdrawals must be observed, and that oil should not be produced faster than refiners can use it. In most parts of the world, neutral observers administer production quotas much as the Oil and Gas Conservation Board does in Alberta.

Present Producing Conditions

In western Canada quotas are far below the Maximum Permissible Rate and producers in the more prolific fields have their income curtailed. Small companies are feeling a serious economic pinch and even the larger companies have greatly reduced profits. We crave the use of a crystal ball to enable us to forecast the future. With Professor Pitcher's 1920 forecast of Alberta coal production in mind we hesitate to predict the future even to the extent of the Gordon Commission report. Some straws in the wind are the acceptance by President Eisenhower that Canadian oil may enter the United States without quota restrictions. The Chase Manhattan Bank studies predict growth in demand for oil that will be adequate to absorb all the oil that can be produced on the continent within a very few years.

Several European countries are searching for oil and finding it, and the tendency is toward use of national energy supplies even if nationally produced energy costs more than imported fuels.

Alberta's crude oil reserves at the end of 1958, estimated at 3 1/6 billion barrels, if drawn at the uniform rate set for May 1959 are good for 28.5 years if no further discoveries or extensions are made.

Natural Gas Reserves and Marketing

Natural gas is the most convenient source of domestic heat for cooking, water heating and space heating. Yet it suffers the greatest handicaps of any heat source. It needs continuous pipe from the well to the appliance and this natural handicap is only the start, for politics gets a field day with every covetous farmer trying to get gas delivered to his farmhouse at the expense of the owner of the fuel. City governments bring pressure on the Provincial government to interfere with marketing, and the Canadian government again puts a finger in the pie.

Alberta reserves were set at 25.6 trillion cubic feet as of January 1, 1959, and gas demand within the province over 30 years, with allowance for increasing use is now estimated at 8.5 trillion or about 90 years supply. There is prospect of large future discoveries to be added to presently known reserves.

Fortunately for those who own gas wells, Trans-Canada Pipe Lines has a pipeline delivering gas as far east as Montreal and Westcoast Transmission has a line from Peace River to Vancouver and is delivering gas to the western United States.

As we write, the Alberta government has granted permission to Alberta and Southern Gas Co. and to Westcoast Transmission to deliver gas destined for the northwestern United States and as far as San Francisco, but approval by the Dominion is also needed, as well as approval by the Federal Power Commission to import.

Thus there seems to be hope for companies to realize on assets, some of them dormant for 30 years.

Summary

Alberta has very large reserves of energy sources and the probability exists that known reserves are but a fraction of the total.

As population of the province grows, utilization of energy within the province will grow.

Pipelines enable our oil and gas to reach wide markets. At present a world surplus of producible oil faces our industry and much business sense is needed to market what we can produce.

Regardless of present potential to produce oil, exploration must continue if the industry is to keep resilient and science must be used to the full if total cost of finding and developing oil in Alberta is to be competitive.

An educator speaking recently on the training of scientists quoted Sir Cyril Hinshelwood as follows: "Science is an imaginative adventure of the mind seeking truth in a world of mystery."

Only occasionally does mankind develop a Newton to formulate the Laws of Motion, a Darwin to explain the Origin of Species, a Rutherford to dissect the atom or an Einstein to relate mass to energy. But there is room for many to make geology an adventure of the mind.

In the papers to follow and in the two days of field observations, planned for this conference, we will be hearing about and seeing some of the locations of energy sources.

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ALBERTA AND FOSSIL VERTEBRATES

WANN LANGSTON, Jr.[1]

Abstract

The history of the backboned animals is very incompletely documented by the fossil record in Alberta. Yet in point of time encompassed, the Alberta record provides more glimpses of this history than does that of any other province.

Palaeozoic vertebrates in Alberta consist of a handful of fish remains from Devonian and Mississippian rocks. Because of the absence of genetically appropriate sediments, chances of finding terrestrial Palaeozoic vertebrates in Alberta are not good, but additional marine fossils can be expected.

Except for the late Cretaceous dinosaur faunas, without parallel elsewhere in the world, much the same must be said for the Mesozoic vertebrate records. The possibility of amplifying the late Jurassic and early Cretaceous records exists in the southwestern part of the province.

Paleocene vertebrates are known from several localities; specimens consist of a few tiny mammal teeth, scraps of fish, reptiles, and an amphibian. There is but one bone attributable to a post Paleocene Tertiary vertebrate from Alberta. The probability of expanding the later Tertiary record is virtually nil, owing to absence of sedimentary deposits of appropriate age and consistency.

Quaternary fossils occur, but as yet are poorly known. Prospects for improving this situation are moderately good, however.

Introduction

More than three quarters of a century have passed since R. G. McConnell first discovered dinosaur bones in Alberta, at Scabby Butte north of Lethbridge. From then on the spectacular badlands, eroded in Cretaceous deposits along major Alberta rivers, have attracted the attention of North American vertebrate palaeontologists. The result has been the assembly of the world's most varied collection of late Cretaceous dinosaurs. But the upper Cretaceous record of fossil backboned animals is not limited to these spectacular monuments to one of nature's greatest failures. In fact remains of a large number of physically insignificant, but in the balance more successful, creatures have been recovered from the dinosaur beds of Alberta. These, however, as a rule receive only passing recognition, and dinosaurs have become almost synonymous with Alberta vertebrate palaeontology in the popular mind. Nor is the record of vertebrate history in Alberta confined to the closing phases of the Age of Reptiles. A brief review of this record in the context of the history of backboned animals generally, may serve to bring the Alberta dinosaurs into proper perspective and provide a framework for viewing the fossil record of life in Alberta.

Included with this paper are a number of Figures showing Alberta fossil vertebrates.

A History of Alberta Fossil Vertebrates

Little is known of the earliest animals with bony skeletons whose remains are first recorded in rocks of Ordovician age. They were small armoured fish-like creatures that had not yet evolved hinged jaws, which together with a backbone are the common hallmarks of modern vertebrates, — the lampreys excepted. Although these primitive Ordovician fishes have been reported from nearby states (South Dakota, Wyoming and Montana), no Ordovician vertebrate has yet been recorded from Alberta rocks. The succeeding Silurian Period was a time of evolutionary consolidation, when the new and relatively undiversified bony creatures were occupying varied ecologic niches within their aquatic sphere. Silurian vertebrates are better known throughout the world than their Ordovician predecessors, but again, none has been found in Alberta.

It is not until the mid-Devonian, when a highly diverse fish fauna with unmistakable resemblances to modern types was just over the evolutionary horizon, that the first Alberta records of fossil vertebrates occur. Nothing approaching the world-famous Upper Devonian fish faunas of eastern Canada, the "Old Red" of Europe, or the Cleveland shales, has been found; but important elements of each of these faunas have been recognized from fragments in Alberta Devonian rocks. From the basal part of the presumed middle Devonian Elk Point group at the Red Earth oilfield, we have the small armoured predaceous fish *Coccosteus,* an arthrodire. Other specimens occur in the Ghost River formation on End Mountain implying synchroniety with the Elk

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Point beds. Fragmentary bony plates of the huge allied *Dinichthys* have been collected from the latest Devonian Minnewanka limestone near Exshaw. This animal was among the largest vertebrates of the day, attaining a length of perhaps twenty feet. Arthrodires were evidently swift if clumsy swimmers whose extinction near the close of the Devonian Period is related, according to some, to the almost simultaneous disappearance of the eurypterids. Another record of a large arthrodire occurs in the Exshaw formation at Jura Creek suggesting that there the rocks are of pre-Mississippian age. From the somewhat older Perdrix formation at North Saskatchewan River Gap in the Brazeau Range, there have come remains of the small peculiarly armoured bottom-feeding fish *Bothriolepis,* among the last survivors of a tribe that left no descendents beyond Devonian times.

It was in the Devonian Period that a major evolutionary milestone was reached: amphibians, creatures that except for reproductive processes could be at home on land as well as in the water, appeared and paved the way for conquest of land and air. Although a doubtful record of one of these early amphibians — almost indistinguishable from its fish ancestors — has been reported from eastern Canada, no trace of this or of later Palaeozoic amphibians has been found in Alberta.

The Carboniferous life of Alberta is visible only in the briefest of glimpses. The advent of the reptiles, the first vertebrates which as a group were able to divorce their life-history completely from the water, occurred without leaving a trace in the sediments of the province. The fossil record here consists presently of less than a handful of fish remains. Mississippian vertebrates are represented by a set of crushing teeth of *Scoliorhiza* from the Rundle limestone at upper Rocky River, and by some of *Helodus* from the lower part of the Banff formation at Roche Miette, both collected over a quarter of a century ago. These fish represent an adaptive type that has evolved independently on numerous occasions (convergent evolution), and exists today in the Port Jackson shark, a "living fossil" of Australian waters. In this the teeth, usually of uniform construction in fishes, are differentiated to permit a division of labour in feeding. Those in the back part of the jaws form broad crushing surfaces, while teeth farther forward are organs for grasping.

No Pennsylvanian vertebrates have so far been reported in Alberta; nor is there any trace of the highly varied amphibian and reptile faunas that are so important in Permian deposits elsewhere in North America and the Old World.

The Alberta record of Palaeozoic life is thus most inadequate and unspectacular. Vertebrate fossils are generally uncommon in carbonate rocks, relative to the volume of these sediments the world over; the red-bed flood-plain and lagoonal shale facies that have produced the preponderance of late Palaeozoic tetrapods in other parts of the world seem to be undeveloped in Alberta (or anywhere else in Canada except in the Maritime region). Furthermore, accessible exposures of genetically appropriate bedrock are fairly limited in extent. This unhappy appraisal, however, does not mean that the search for fossil vertebrates should be abandoned as hopeless, but rather suggests that it must be intensified if worthwhile results are to be obtained.

Except for its latest chapters, the history of Mesozoic life in Alberta is little more complete than that of the Palaeozoic. Again the preponderance of carbonate rocks and the absence of the redbed, deltaic and lagoonal facies are mainly responsible.

The early Triassic Spray River formation has yielded a fish fauna from the vicinity of Banff. Interestingly, had these rocks been dated on the evolutionary aspect of their fish fauna they could have been assigned a Palaeozoic rather than an early Mesozoic age. Included are a predaceous creature called *Saurichthys* whose long body and slender snout are reminiscent of the later garpikes. There are several primitive bony fishes: *Elonichthys, Acrolepis, Platysomus,* and *Lambeichthys.* The last two were deep-bodied fishes adapted for life in quiet waters; the first two were of more "conventional" herring-shape and presumably were more active swimmers. All were members of the large and varied, mainly Palaeozoic, group of paleoniscoids among which were ancestors of the majority of modern fishes. They were covered by "ganoid" scales, thick, flat, usually rhomboidal structures with dense, shiny, often sculptured outer surfaces. Somewhat comparable scales occur today in the garpikes. A lobe-finned fish *Coelacanthus* is also present in this assemblage. It is a crossopterygian, one of the group of fishes that from our point of view was of great evolutionary significance because it contained the ancestors of all vertebrate land animals. Popular attention has been focused on the crossopterygians in recent years by the discovery that the coelacanth, presumed extinct since Mesozoic times, still lives in African seas.

Large reptilian "dolphins," the ichthyosaurs, are abundantly preserved in Triassic rocks of British Columbia, and they are reported near the Alberta-British Columbia boundary west of Banff. But to date no good specimens of Triassic (or Jurassic) marine reptiles have been obtained in Alberta. Chances of finding some seem excellent, however. On the other hand prospects of discovering the spectacular stegocephalian amphibians. phytosaurs, primitive dinosaurs, or mammal-like reptiles that characterized the land life of Triassic times are virtually nil.

But if the Triassic record of .vertebrates in Alberta seems meagre, evidence of Jurassic history is practically non-existent: the age of the greatest dinosaurs and earliest mammals is represented by fossil egg capsules, termed *Chimaerotheca,* of an early ratfish. These are from the Nikinassin formation exposed on Sulphur River, where they are said to be sufficiently common for use as "index fossils." It is not improbable that other Jurassic vertebrates will come to light in Alberta, either in the extensively developed marine sequences where fish ichthyosaurs (common in British Columbia Fernie deposits), and plesiosaurs can be expected, but also in the southwestern part of the province where Jurassic and Lower Cretaceous terrestrial strata occur.

Lower Cretaceous time is well represented lithologically and palaeobotanically in Alberta by the Kootenay and Blairmore beds. Why these sediments have not yielded vertebrate fossils in the face of careful scrutiny over the years is an enigma not without parallel in vertebrate palaeontology. (A smaller dinosaur *Laosaurus* previously reported from the Blairmore near Burmis really came from Oldman beds). That vertebrates ancestral to the Upper Cretaceous faunas of the Red Deer and associated districts may yet be discovered is a hope fraught with interesting possibilities.

In contrast to earlier and subsequent sedimentary deposits, the Upper Cretaceous dinosaur beds of Alberta are palaeontologically without equal anywhere in the world. Here a remarkably varied cross-section of the lowland vertebrate life of the dying stages of the Age of Reptiles is available to us and concerted exploitation for 50 years has yielded one of the best potential examples of a vertebrate chronofauna known.

The principal beds which contain dinosaurs and associated vertebrates are the Oldman (Belly River, Pale Beds) and Edmonton formations, especially where exposed along the Red Deer River from near Stettler to the vicinity of Brooks. Fossil localities are too numerous to discuss in detail but among the more important areas the Drumheller valley, the Steveville (Brooks) area, and the Manyberries region may be cited. Other strata, notably, the upper Milk River, Foremost, Bearpaw and St. Mary River formations have provided interesting discoveries. A list of the fossil vertebrates obtained from these beds is given in the accompanying chart.

The fishes are mainly fresh and brackish water forms. *Lamna* and *Palaeospinax,* and possibly *Myledaphus* were sharks. Although present-day sharks are mostly marine fishes there are numerous examples of ancient sharks inhabiting brackish and fresh water. *Lamna* which still lives in oceanic waters is a heavy bodied "mackeral" shark. ,Its teeth occur in the brackish or marine beds of the Foremost, brackish-water sediments of the Oldman, marine shales of the Bearpaw, and brackish-water facies of the Edmonton formation. *Palaeospinax* was evidently a stream-dweller about which little is known, except that the body was slender, the tail long. *Myledaphus* is known only from its peculiar double-rooted crushing teeth, but these are perhaps the commonest vertebrate fossils in the formation discussed. It may have been related to the rays, or was possibly a pavement-toothed shark. *Ceratodus* was related to the living Australian lung-fish. *Acipenser* is the sturgeon which evidently appeared in the late Cretaceous, and *Lepisosteus* is the alligator gar of garpike, the voracious and once ubiquitous "living fossil" whose beautiful shiny diamond-shaped scales are common fossils in many Northern Hemisphere Upper Cretaceous and Tertiary lagoonal sediments. This fish survives today in the Mississippi River drainage. It is related to the very different *Pappichthys, Kindleia,* and *Stylomyleodon* which are represented today by *Amia,* the bowfin, of the quiet fresh waters of northeastern United States and Canada. These fishes may have occupied a Cretaceous habitat not unlike their modern relatives.

It is interesting to note that only one amphibian *Scapherpeton* is known from the formations discussed, that its geologic range is long, and that we do not even know its precise systematic position. Probably it was a salamander of some sort. Frogs and toads were in existence during late Cretaceous time and since they are among the most successful of vertebrates it is difficult to explain their absence from the Upper Cretaceous rocks of Alberta. Their bones are tiny in

comparison with those of the dinosaur, and it is possible (but not very likely) that they have simply been overlooked. Most frogs and toads live around shallow water and it is more probable that most dinosaur beds of Alberta were deposited in deeper water. Also frog bones are delicate and not good candidates for fossilization.

Turtles are very numerous in some deposits where a host of lake and stream-dwellers occurs. *Aspideretes* was a close relative, indeed propably an ancestor, of the modern soft-shelled turtles of Asia and North America. *Boremys,* though not closely related to the living snapping turtles bore them a close physical resemblance, and probably made a living in similar fashion. Largest of the turtles was *Basilemys* whose massive shell was over an inch thick in places. In life the creature may have weighed two hundred pounds. *Compsemys* is notable for having a shagreen of dense bird-shot sized granules covering the shell instead of the usual broad scales. In fossil form, fragments of these shells are readily distinguished from any other turtle, as are those of *Aspideretes* and *Basilemys* with their characteristically pitted shell surfaces.

Two plesiosaurs, *Cimoliosaurus* and *Leurospondylus,* the latter possibly descended from the first, occur in the Oldman and Edmonton formations respectively. These were both long-necked varieties called elasmosaurs, whose fish diet was obtained by a tiny head which darted at the end of an absurdly long neck, — the broad body and flippers serving as a sea-anchor. Both these plesiosaurs apparently were at home in brackish waters and evidently confined to North America, but relatives of theirs ranged the oceans. Other plesiosaurs have been found in the Foremost formation along Milk River, and in Chin Coulee, and remains occassionally appear in deeper marine Bearpaw beds. Some of these were short-necked, long-headed plesiosaurs that apparently were stronger swimmers than the elasmosaurs and obtained their food by overtaking it.

Crocodiles are surprisingly few in the Alberta Upper Cretaceous; one genus only, *Leidyosuchus,* has been recognized. This animal, which attained a length of about six feet, differed little from modern crocodiles. On the assumption that animals so similar in physical appearance probably had comparable physiological characteristics it is logical to conclude that late Cretaceous temperatures in Alberta were comparable to those where crocodiles exist today, and that the ground never froze in winter.

A remarkable reptile of uncertain relationships was *Champsosaurus.* It had an alligator-shaped but unarmoured body. A long slender snout armed with many sharp teeth doubtless assisted in catching fish. Evidently *Champsosaurus* spent most of its life in the water (its eyes were on top of the head) where it probably competed with the resident crocodiles, and possibly accounts in part for the local scarcity of these. Both crocodiles and champsosaurs as well as turtles, snakes, and lizards survived the great reptile extinctions at the close of the Age of Reptiles. *Champsosaurus,* however, succumbed to causes unknown in the early Tertiary.

Snakes are unknown from the Alberta Cretaceous and lizards are not abundant. A heavy-bodied presumably armoured lizard, *Palaeosaniwa,* is reported from the Oldman formation, and from near Grande Prairie a jaw of a small iguana, *Chamops,* has been recovered from member "B" of the Wapiti formation, an Edmonton correlative. Both are among the oldest of "modern" lizards. The long-jawed *Polyodontosaurus* from the Oldman formation once thought to be a lizard is now known to be the carnivorous dinosaur *Troodon.*

The dinosaurian fauna of Alberta is so diverse that detailed discussion is impossible here. The carnivorous dinosaurs ranged from chicken-sized *Troodon* to gigantic *Gorgosaurus* and the even larger *Tyrannosaurus* (whose known remains from Alberta are fragmentary). These animals subsisted upon the slower herbivorous dinosaurs of the time. Among these were the hoards of mainly acquatic duck-billed hadrosaurs that evidently enjoyed the comparative safety of the lagoons where presumably the dry-land carnivorous dinosaurs could not follow them. The ceratopsians (horned dinosaurs) and the nodosaurs (armoured dinosaurs) were protected to some degree by possession of horns and various bony shields on the head and body. The latter have been referred to as reptilian tanks, — a reference to the masses of thick spiked and nodular armour plate, and a tail with a club on the end, that must have been an efficient defense against the exposed shins of the long-limbed carnivorous dinosaurs.

These dinosaurs inhabited the lowlands and savannas on the broad swampy deltas that were forming just east of the ancient Rocky Mountains. Of the animals that existed at higher and dryer altitudes we have only traces. Such may have been the small heavy-bodied vegetarians *Thescelosaurus* and *Parksosaurus,* and light-bodied, swift-footed carnivorous dinosaurs (*Struth-*

riomimus, Ornithomimus, etc.). *Ornithomimipus* from the Edmonton formation is named from a footprint of one of these. The remarkable thing about these dinosaurs is that although obviously derived from carnivorous stock they lacked teeth in jaws that had become more bird-like than reptilian. Their diet is unknown, but certainly no longer included flesh; berries, nuts, or eggs may have been the staples.

Among the strangest of dinosaurs were the small herbivorous "domeheads" *Stegoceras* (once termed Troodon). These animals which occur in relative abundance in the Foremost formation at Chin Coulee, but also in most other dinosaur beds in Alberta, had a massive bony dome atop the head. This was surrounded by grotesque bumps and knobs. *Stegoceras* was evidently not a lowland dinosaur, because, except for a partial skeleton, only its skull domes which resist disintegration have ever been found.

An interesting fauna recently obtained from the St. Mary River formation (an Edmonton correlative) near Barons contains the customary *Myledaphus,* a small shark, *Lepisosteus, Champsosaurus, Aspideretes* and other turtles, carnivorous and duck-billed dinosaurs and various ceratopsians. One of these was *Pachyrhinosaurus,* possibly descended from *Centrosaurus* found in the Oldman formation. Instead of the usual horns that are the trade marks of ceratopsians this animal had a thick mass of bone on top the skull. The picture of this ponderous beast, twice as large as rhinoceros, "bulldozing" trees in search of food among the roots is a facinating one. Tiny mammal teeth are also present in these deposits recording the prescence of opossums. A mosasaur, one of the great Cretaceous marine lizards, was found at Scabby Butte in 1957. This discovery would have been expected in the marine Bearpaw sediments where in fact mosasaurs do occur, but in the presumed brackish or freshwater deposits of the St. Mary River formation it was surprising.

A fauna from the Saunders formation in the Foothills has a strong Foremost and Oldman flavour with *Myledaphus, Lepisosteus, Basilemys, Compsemys, Aspideretes,* a crocodile and various dinosaurs. The Saunders formation is transitional into the Tertiary System and contains in its upper parts Paleocene mammals.

The dinosaurs and associated vertebrates of the Oldman and Edmonton formations constitute a partial chronofauna, — a fauna whose evolution can be viewed in essentially the same geographic region at succeeding times. Ancestor-descendent relationships are apparent in such evolutionary lines as *Gorgosaurus-Albertosaurs-Tyrannosaurus, Prosaurolophus-Saurolophus, Chasmosaurus-Anchiceratops,* and possibly *Dyoplosaurus-Ankylosaurus.* Many instances of ecological replacement in changing environments are suspected, for example *Struthiomimus* by *Ornithomimus, Kritosaurus by Saurolophus,* earlier ceratopsians and armoured dinosaurs by *Triceratops* and *Ankylosaurus.* This picture should become more complete with further study.

Aside from its abundance and variety the dinosaurian fauna of the Alberta Cretaceous is interesting because of its palaeogeographic implications. The amphibious duck-billed dinosaurs lived in Europe and all over North America. Identical or very similar genera occur in Alberta and Asia. Since these dinosaurs evolved very rapidly temporal correlation is obvious. *Tyrannosaurus* and *Gorgosaurus* also occur in Asia. These beasts were bipedal and carried their heads high. Presumably they were capable of wading shallow waters. Contemporaneous armoured dinosaurs while abundant in Asia and Europe seem not to have close ties with any in Alberta, or vice-versa. Large horned dinosaurs have not been certainly recognized in Asia, although the small North American *Leptoceratops* is related to the similarly small *Protoceratops* of the Gobi Desert. It is seemingly more primitive than the Asiatic animal although of much more recent vintage. These facts of dinosaurian distribution point to the existence of a "sweepstakes" route of dispersal between North America and Asia during the final phases of the Age of Reptiles. Over this route passed dinosaurs that could wade, float or swim, but those which were unable to do this safely, whose heads were too close to the ground were unable to negotiate the apparently shallow water barriers. There appears to have been great selectivity in dispersal at this time. Thus fresh water vertebrates may have had no taste for sea water and avoided the passage while land-living mammals may have crossed the barriers by rafting.

Only one bird *Coenognathus* is reported from the Alberta Cretaceous. This was a large, presumably flightless animal with a massive head and powerful beak. Large flightless birds have evolved on nearly all continents from time to time when native predatory animals did not provide successful competition. *Coenognathus* appears to be the first such instance in history.

The first mammals evolved in the Jurassic Period, and as yet we have only tantalizing glimpses of Mesozoic mammals generally. Of those listed from the Oldman and Edmonton formations *Cimolomys* and *Ptilodus* were multituberculates (to be discussed subsequently). *Eodelphis* and *Delphodon* were opossums, the first not unlike its living North American descendent. The most complete specimen of a Cretaceous mammal from Alberta is a lower jaw and part of a cheek bone of *Eodelphis!* Others are merely teeth and bits of jaws.

With no proven exceptions the dinosaurs and most of their reptilian associates had disappeared from the terrestrial scene by the beginning of the Tertiary Period. In their places were left small and at first insignificant mammals and birds. These commenced an extensive adaptive radiation in the dying phases of the Mesozoic and this increased in momentum throughout the first half of the Tertiary Period. During the Age of Mammals virtually all the ecologic niches once filled by the extinct reptiles became occupied by mammals and birds. The history of the Age of Mammals is well known on a world-wide basis, the known species numbering thousands. But in Alberta only the Paleocene Epoch is at all represented by fossils. The faunal list of the Paskapoo formation is impressive at first sight, but then it is recalled that except for turtles and champsosaurs all known specimens would scarcely fill a double handful, so tiny and fragmentary are they.

Among fishes, relatives of the bowfin and the garpike are reported from several localities. The problematical salamander *Scapherpeton* reappears. The lingering remnants of the Reptile dynasty — crocodiles, champsosaurs, and turtles (lizards and snakes are unreported) — lend an archaic aspect which nonetheless is actually more remindful of modern faunas than are the mammals.

Of mammals *Eucosmodon, Ptilodus, Ectypodus, Parectypodus* and *Catopsalis* are among the last survivors of one of the earliest groups — the multituberculates — whose pedigree is traced as far back as the Jurassic Period. These may be likened to rodents. Though not closely related to them they represent a common evolutionary phenomenon called parallelism in which distantly related organisms in adapting to similar modes of existence acquire similar physical characteristics. Alberta multituberculates were tiny creatures, much smaller than the giants of the group which were comparable in size to a beaver.

Insectivores, represented today by hedgehogs, shrews, and moles, first occur as fossils in Cretaceous rocks of the Gobi Desert. In the Alberta Paleocene they are represented by *Elpidophorus, Propalaeosinopa, Diacodon* and *Leptacodon.*

Today's ruling order, the Primates, which appeared in the Paleocene Epoch, has two members, *Plesiadapis* and *Pronothodectes* in the Paskapoo deposits. These were small lemur-like creatures of possible arborial habits and omnivorous diet.

Chriacus and *Claenodon* were carnivores. The last bulked as large as a bear and possibly made its living in similar fashion, — another example of parallelism.

Ancestors of later hoofed mammals were the condylarths represented by *Tetraclaenodon, Ectocion,* and *Meniscotherum.* Although clearly evolving in other directions these creatures still bore strong reminders of their carnivorous and insectivorous ancestry in the presence of clawed feet and sharp teeth. The sheep-sized *Phenacodus,* another condylarth, had small hoofs.

The Saunders formation contains a large (for the day) hoofed beast, *Caenolambda,* representing history's first radiation of heavy-bodied hoofed mammals. Also there is *Chriacus* which occupied a position near the end of the first broad adaptive radiation among carnivorous mammals.

Except for a nondescript bone or two from British Columbia and a few reptiles from Saskatchewan, this is the record of Paleocene vertebrates from Canada. The most productive localities are near Cochrane and below the town of Red Deer. There are also localities within the city limits of Calgary and near Aldersyde, but little has come from any but the first and last in recent years.

Paleocene faunas of Alberta represent mainly lowland and aquatic assemblages. Relationships of the animals lie with North American Tiffanian and Clark Forkian genera: only *Plesiadapis* and possibly *Ectypodus* occur in Europe.

Beyond the Paleocene Epoch, the currently known Tertiary vertebrate record from Alberta comprises one specimen — an ankle bone of a cosmopolitan Pliocene (or early Pleistocene) horse *Plesippus* obtained recently from the Hand Hills Conglomerate. Sedimentary rocks of appropriate age simply do not exist in sufficient quantities in Alberta. The extensive gravels in the Cypress Hills of Alberta have produced no vertebrates owing probably to their excessive coarseness.

Quarternary vertebrates occur at widely spaced, mostly gravel, deposits. They consist of extinct species of horses, bison, musk-ox, wolves, a mountain sheep, etc. Teeth and tusks of the great mammoths are relatively common, but not as abundant as in the region to the south. And the forest-dwelling mastodon is practically unheard of in the province.

Such is the recorded history of animals with backbones in Alberta. Only brief glimpses of the life of the past are available through fossils, but in point of time involved the record from Alberta is more extensive than from any other Canadian province. Future discoveries should help to bridge some gaps in this history, but such is the nature of missing links that with the discovery of each new one, two more are created.

REFERENCES

Space is not available to list the voluminous literature dealing with Alberta vertebrate palaeontology. The reader is referred to the standard geological and palaeontological bibliographies where citations under the following authors may be of interest: B. Brown, E. D. Cope, C. W. Gilmore, D. S. Jordan, E. M. Kindle, L. M. Lambe, W. D. Mathew, H. F. Osborn, W. A. Parks, P. E. Raymond, L. S. Russell, G. G. Simpson, C. M. Sternberg, R. M. Sternberg, and P. S. Warren.

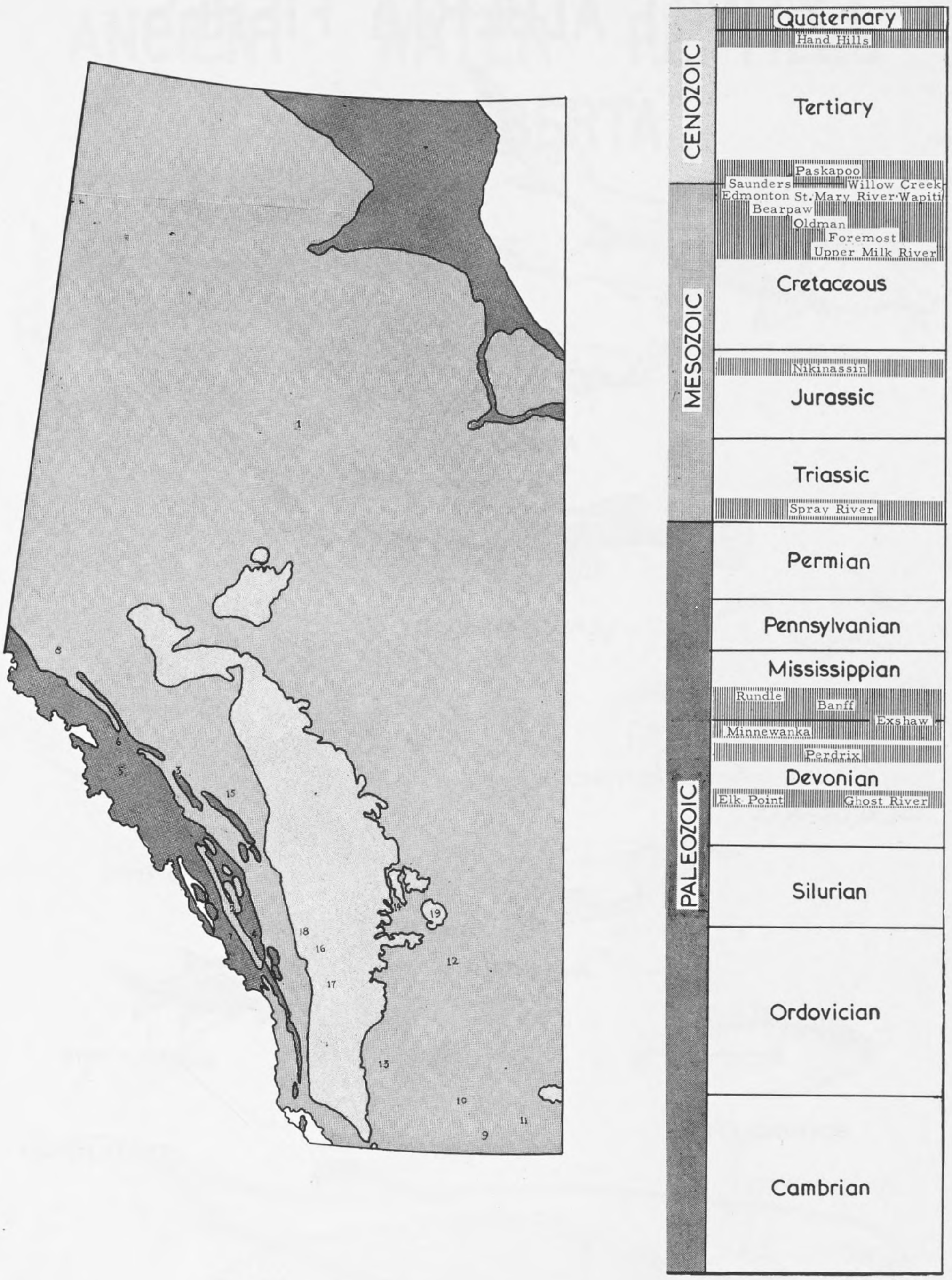

FIGURE I

Generalized map of Alberta showing important fossil vertebrate localities in relation to Palaeozoic, Mesozoic, and Cenozoic outcrop areas. Patterns correspond to the columnar section at right. (1) Red Earth oil field (subsurface), (2) End Mountain, (3) North Saskatchewan River Gap, (4) Exshaw; — all Devonian occurrences. (5) Upper Rocky River, (6) Roche Miette; — both Mississippian. (7) Banff; — Triassic. (8) Sulphur River; — Jurassic. (9) Milk River, (10) Foremost, (11) Manyberries, (12) Brooks (Steveville), (13) Nobleford (Scabby Butte), (14) Drumheller; — all Upper Cretaceous. (15) Saunders Creek, (16) Calgary, (17) Aldersyde, (18) Cochrane; — Paleocene. (19) Hand Hills; — Pliocene. Quaternary vertebrates occur generally throughout Alberta in gravel deposits. The columnar diagram at right shows relative positions of vertebrate-bearing rock units in the stratigraphic column.

EXTINCT ALBERTA FISHES

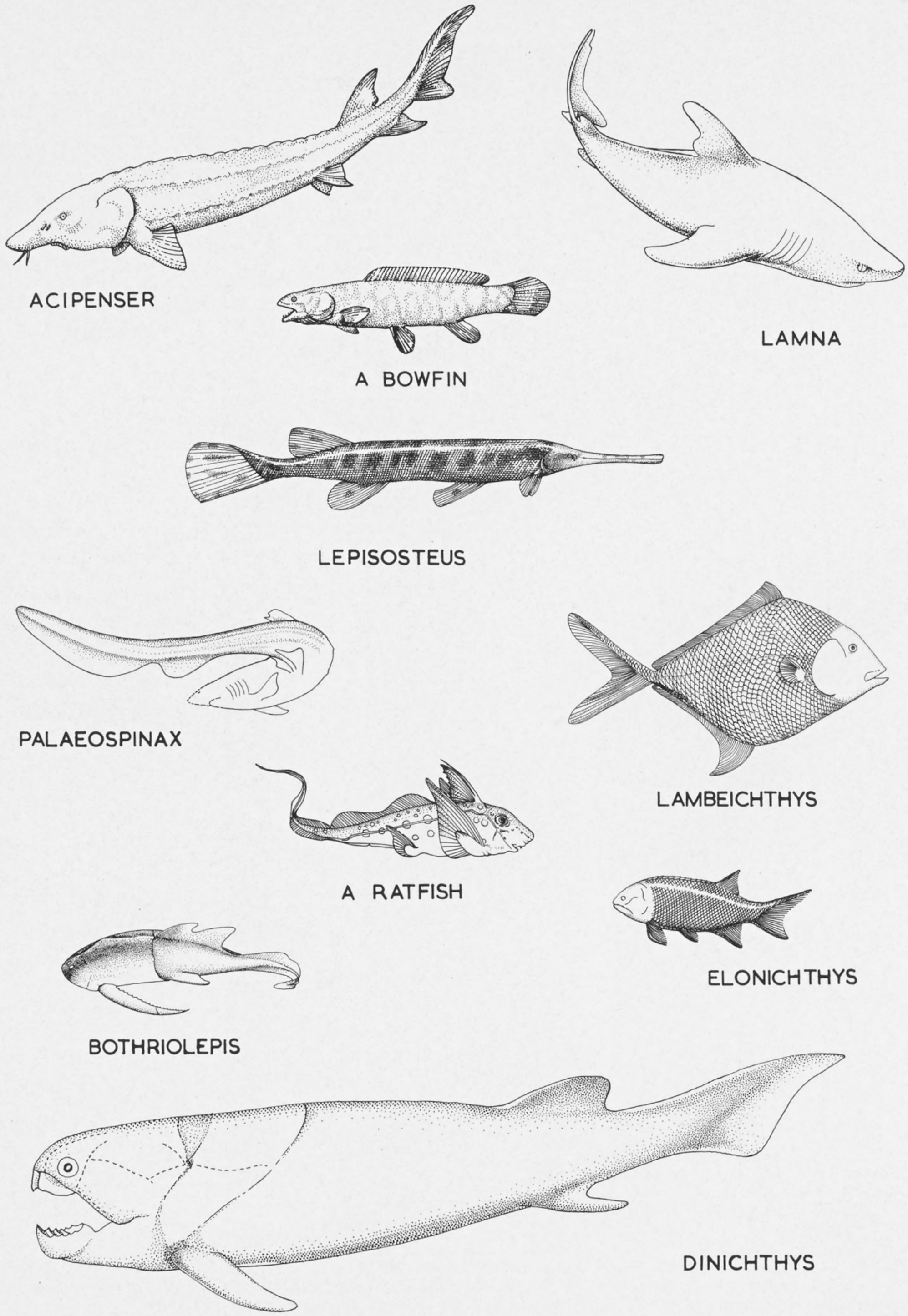

FIGURE 2

Relative size of fishes is suggested, but drawings are not exactly to scale, for example, **Dinichthys** in life was at least 20 times as large as **Bothriolepis.** Only the tail of **Palaeospinax** is known: the remainder of the reconstruction is hypothetical. These and subsequent drawings are by P. R. Haldorsen.

ANCIENT WATER REPTILES OF ALBERTA

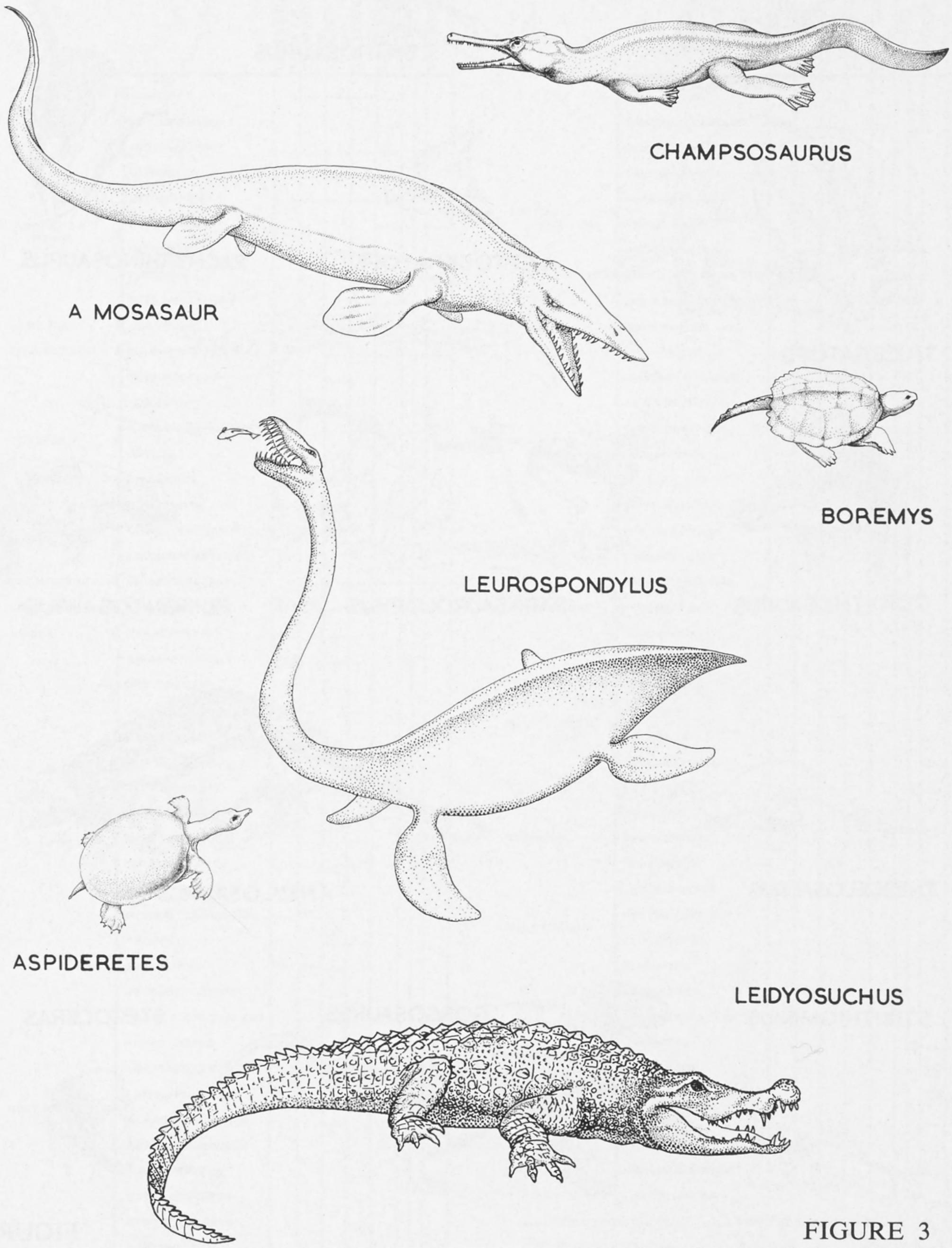

FIGURE 3

Relative size of reptiles is suggested, but drawings are not exactly to scale, for example, **Leurospondylus** in life was at least twice as long as **Leidyosuchus.** The head of **Leurospondylus** is unknown; the reconstruction is based on related species.

ALBERTA DINOSAURS

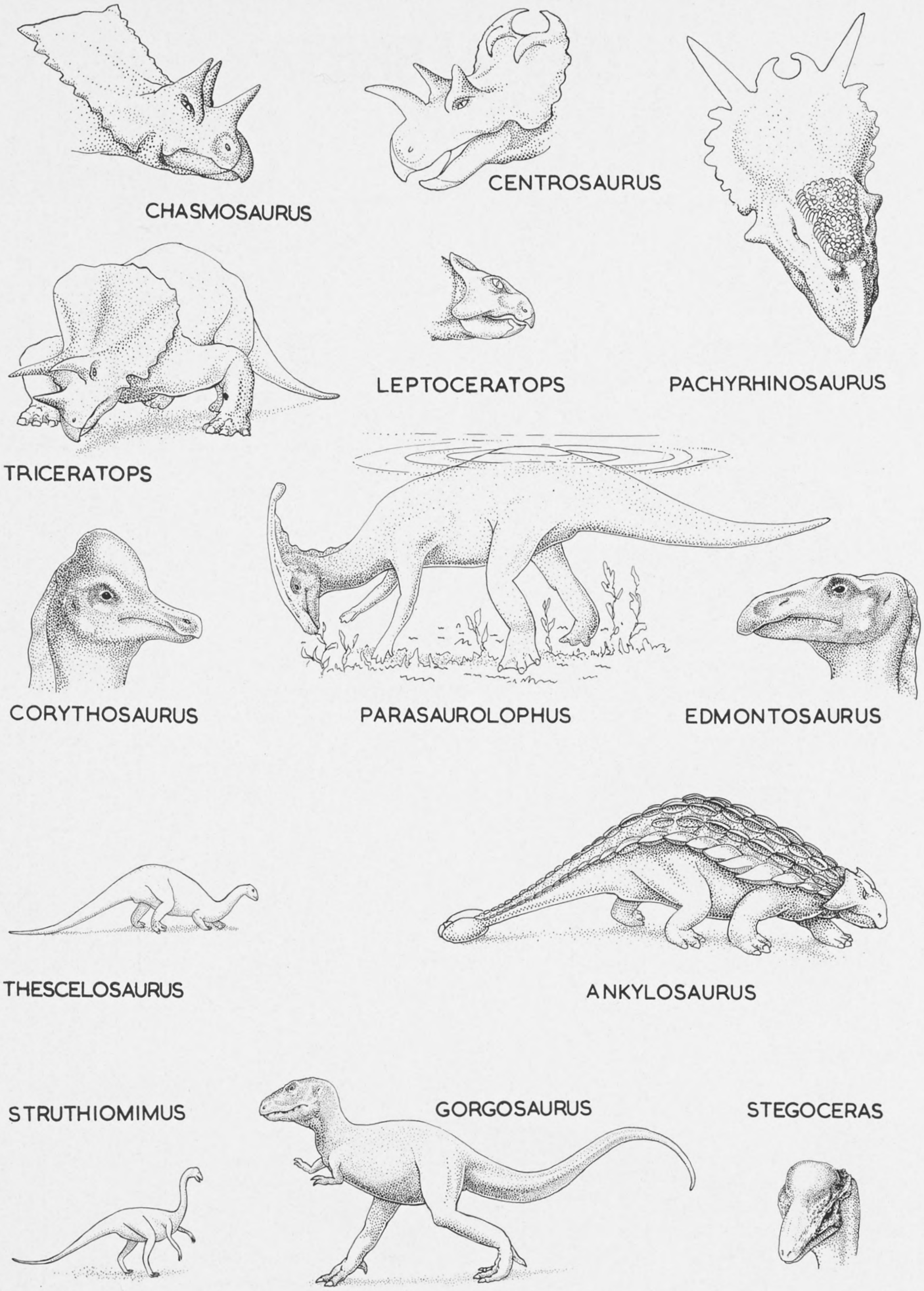

FIGURE 4

Only a few species are shown, but all major groups are represented. Relative size of dinosaurs is suggested in the full-body reconstructions, but drawings are not exactly to scale. The back part of the head of **Pachyrhinosaurus** is reconstructed on the basis of circumstantial but presumably reliable evidence obtained at Scabby Butte.

FOSSIL VERTEBRATES OF SOME ALBERTA LATE CRETACEOUS AND EARLY TERTIARY DEPOSITS

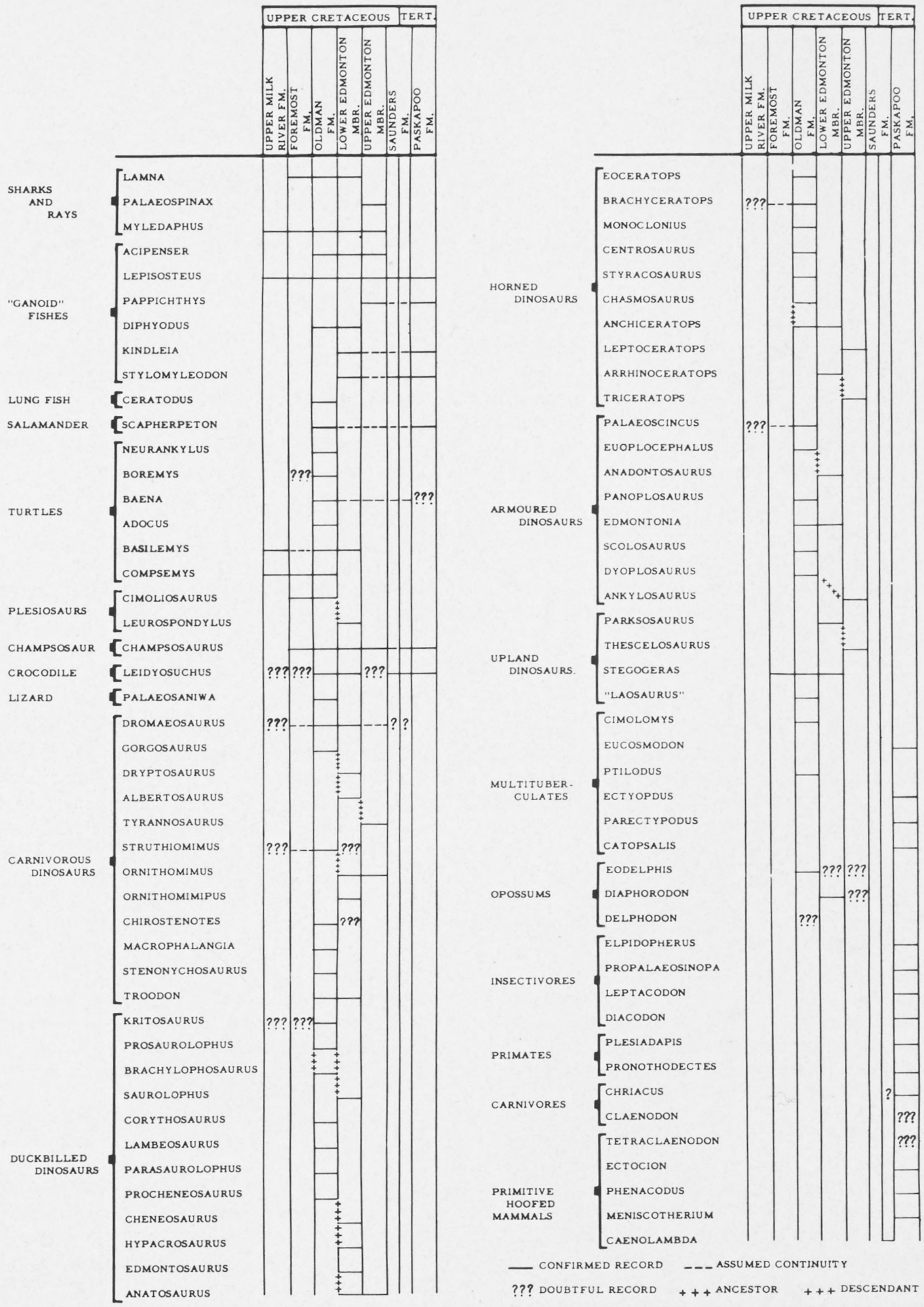

FIGURE 5

GEOMORPHOLOGY OF THE DRUMHELLER-MORRIN AREA, SOUTH-CENTRAL ALBERTA

A. J. BROSCOE AND R. H. BARTON [1]

Abstract

The Drumheller-Morrin Area is underlain by Upper Cretaceous and Tertiary marine, brackish-water and continental sediments, dipping very gently to the west into the Alberta syncline. The bedrock is obscured by two till sheets and a disintegration moraine, which includes central-depression prairie mounds, moraine plateaus, and disintegration ridges. Extensive Pleistocene lake deposits accumulated in three lake stages at successively lower levels. The rapid down-cutting by the Red Deer River, probably in post-glacial time, is thought to be the result of an increased discharge due to diversion of the present headwaters of the Red Deer River into the present system north of the town of Red Deer. Rapid erosion of the nonresistant Edmonton formation exposed in the valley walls resulted in the formation of spectacular badlands which are undergoing further erosion at the present time.

Introduction

The Drumheller-Morrin Area extends from eight to twelve miles on either side of the Red Deer River, from Twp. 27 through Twp. 31, Rge. 18 through Rge. 22, W4M, Alberta. This general description of the geologic setting and geomorphic features is a compilation from the geologic literature combined with information gained from the study of air photographs and several trips to the area. Understanding the descriptive material will be facilitated by reference to the air photograph mosaic (Pl. I, in back-pocket).

The Red Deer River Valley has been studied geologically by, among others, Allan and Sanderson (1945), and Sternberg (1947). The surficial geology has been mapped in a generalized manner by Bretz (1943), and in detail by Stalker (1955), and Craig (1957). In addition, the soils in the area have been mapped by Wyatt et al. (1943). Soil maps of such recent dates indicate the origin of soil materials and are therefore particularly useful in studies of surficial material and land form distribution.

Geologic Setting

The bedrock immediately under the glacial drift in the Drumheller-Morrin Area consists of Upper Cretaceous and Paleocene sediments which dip generally to the west at a very low angle into the Alberta syncline. The oldest unit to crop out in the described area is the Bearpaw formation, a dark-brownish to gray shale, in part bentonitic, with some sandy beds. The outcrop is restricted to the lower part of the Red Deer River valley, southeast of the junction of Willow Creek and the Red Deer River, Twp. 28, Rge. 18, W4M. The maximum thickness of the Bearpaw shale reported by Allan and Sanderson is 550 feet, but of this thickness only the upper few tens of feet are exposed within the area covered by Plate I. The Bearpaw shale is overlain by the Edmonton formation, which consists of sandstones, shales, coals, and bentonites of fresh and brackish-water origin. The average thickness is approximately 1,000 feet (Allan and Sanderson, 1945). The spectacular badlands along the Red Deer River are developed within the various members of the Edmonton formation. The Edmonton formation is overlain unconformably by the Paleocene Paskapoo formation, a sequence of orange-buff, impure sandstones and gray shales, which rests upon various members of the Edmonton formation. The Hand and Wintering Hills, although outside the mosaic area to the east and south respectively, contain still younger Tertiary sediments, the age of which is not definitely established.

Glacial Geology

Allan and Sanderson (1945), Stalker (1955), and Craig (1957) all describe two horizons of till in the vicinity of Drumheller. Stalker considers the time interval between the deposition of the two till sheets to be very short. The latest advance of ice into the Drumheller area was to the southeast, as indicated by ice flow features on both the Beiseker and Drumheller map sheets. Deglaciation in the area appears to have taken place by stagnation of the ice sheet, with the resultant deposition of typical disintegration moraines, as shown in two patches north and west of Morrin and

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a large area straddling the present Red Deer River Valley between Drumheller and East Coulee. Such features were recently described by Gravenor and Kupsch (1959). During disintegration of the last ice sheet, ice-free areas formed first to the southwest and the general location of the ice face retreated to the northeast. Local remnants of ice blocked the local drainageways, with resulting impoundment of proglacial lakes, typical of the sequence of events occurring in the melting of a stagnant ice sheet on irregular topography. In the Drumheller-Morrin Area, three general lake stages were present, at successively lower elevations. The first stage of lake development consisted of local lakes in the headwaters of Ghostpine, Threehills, and Kneehills Creeks, with the lower reaches blocked by ice. The lake in Kneehills Creek drained for a short time through the Hesketh spillway, the floor of which has a present elevation of 2,950 feet, into a local glacial lake to the south. When the ice melted out of the area between Drumheller and Morrin, the main Lake Drumheller reached its greatest extent, with a water level of about 2,750 feet. It covered the present rolling upland surface in the vicinity of Morrin and Munson and extended part way up the present valleys of Ghostpine, Threehills, and Kneehills Creeks. The final stage consisted of a small lake at about 2,650 feet in the lower reaches of the Red Deer and Kneehills Valleys. When the ice barrier melted below this level, Lake Drumheller was completely drained.

Lake-deposited sands, silts, and clays now obscure the characteristic knobby topography of the morainal material in varying degrees. Generally the lake beds are found at successively lower altitudes from the southwest to the northeast, and are thickest in the deepest parts of the basin. The wide expanse of lake deposits between Drumheller and Morrin indicates the approximate area of the main stage of Lake Drumheller. Allan and Sanderson (1945) described a typical section of lake beds along the Rosebud River as consisting of 18 feet of contorted, varved silts. Stalker (1955) states that the lake deposits consist of silt and clay, commonly varved, although much sand is present. Bedded lake clays and shoreline features are not typical of the lake deposits in the Drumheller area. This would seem to indicate that the glacial lakes in this area were relatively short-lived, and that the annual freeze-thaw cycle considered to be the mechanism for the deposition of varved clays was operative only locally during the deposition of the lake sediments.

The morainal areas north and west of Morrin are characterized by a dense cluster of circular mounds averaging 250 to 300 feet in diameter and up to 30 feet in height. A striking feature of these mounds is that most of them contain central depressions that show up very well on the air photographs. These mounds fit the description of the central-depression prairie mounds of Gravenor (1955) and probably have the same origin. Moraine plateaus, flat-topped hills similar to the mounds in height and with irregular outlines, averaging one-quarter of a mile across, are found scattered throughout the mound area northwest of Morrin. Ice-disintegration ridges, several tens of feet high, approximately 600 feet apart, and up to one mile long, are best developed in the morainal area north of East Coulee. The latter two types of topography were described in other areas by Gravenor and Kupsch (1959). The presence of central-depression prairie mounds, moraine plateaus, and ice-disintegration ridges indicates that this morainal area is an excellent example of a "disintegration moraine", as proposed by Gravenor and Kupsch (1959). This area was previously mapped as part of an "early" Wisconsin end moraine by Bretz (1943).

Origin of the Drumheller Badlands

The Drumheller badlands occur under conditions described by Smith (1958) as favorable for development of badlands. These conditions are expressed in the area under consideration as follows:

1. The Edmonton formation consists of alternating easily eroded clays and less easily eroded beds of sand and volcanic ash. The more resistant beds protect the soft underlying clays, causing differential erosion.

2. Exposed gumbo in the clay dries, cracks, and leaves a mass of loose rubble a foot or more deep. This loose material is rapidly washed away during thunder-showers, leaving steep, vegetation-free slopes. The freshly exposed gumbo now forms another mantle of clay rubble and the cycle continues.

3. High bluffs along the Red Deer River furnish the tributaries flowing down these bluffs with sufficient energy to cause rapid down-cutting and headward erosion of the tributary valleys. As a result, few of the tributaries cutting the bluffs are graded, allowing this erosional pattern to perpetuate itself.

4. Rapid run-off, as a result of the violent thunder-showers, typical of the semi-arid climate of the region, deepens the valleys more quickly than they can be widened. The gully sides therefore remain steep, and the resulting badlands can spread farther away from the Red Deer River. Thus, the Drumheller badlands are the result of rapid erosion of nonresistant sediments by running water in a semi-arid climate.

The intrenched valley of the Red Deer River is one of the outstanding geomorphic features of the Drumheller-Morrin Area. The rapid down-cutting of this valley provided the tributaries with the initial energy they needed to form the badlands. Trenching of a stream valley may be the result of local uplift, or of variations in discharge, sediment load, and sediment fineness. Local uplift of tectonic origin is regarded as unlikely in this area, but regional uplift due to isostatic rebound following deglaciation may have contributed to the trenching. The character of the drainage pattern and of the stream valley of the Red Deer River suggests that the drainage basin tributary to the river upstream from Drumheller was increased considerably in post-glacial time, with a resulting increase in discharge. Two mechanisms could have caused this increase in discharge of the Red Deer River. Allan and Sanderson (1945) suggest that a stream eroding headward west of the town of Ardley captured the entire upper part of the Red Deer River and diverted this great volume of water down the present Red Deer Valley. The writers suggest that the Red Deer River may have been diverted north of the town of Red Deer by downstream damming of the preglacial Red Deer River by an ice front or by morainal materials located to the north. This hypothesis would avoid the necessity of a stream eroding back with no apparent topographic advantage, across the regional strike of the strata. Furthermore, the capturing stream would have had to erode toward the axis of a major syncline, which is considered unlikely. Whichever theory is correct, the important point is that either provides a mechanism for drastically increased discharge of the Red Deer River, with the result that the Red Deer River would seek a gentler gradient, or trench its preglacial valley. The formation of the badlands began immediately after the rapid trenching of the present Red Deer River Valley and is continuing at the present.

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THE GEOLOGY OF THE WESTERN FRONT RANGES SOUTH OF BOW RIVER, ALBERTA

J. L. USHER [1]

Abstract

The Front Ranges sub-province of the Rocky Mountains along Bow River Valley is bounded on the east and west respectively by the McConnell and Castle Mountain thrust faults. It comprises, from east to west, the Fairholme, the Cascade-Rundle, the Norquay-Sulphur-Goat, the Sawback-Bourgeau, and the Pilot-Fatigue Ranges. Excepting the latter, each range is underlain by a major thrust fault; the Pilot-Fatigue Range is closely tied to the Sawback-Bourgeau Range, the two being separated by the Brewster Creek syncline, and the Fatigue thrust fault which has variable but not excessive stratigraphic throw. Topographically the two ranges are distinct.

The stratigraphic section includes the Middle and Upper Cambrian, Lower Ordovician, Upper Devonian, Mississippian, Permian, Triassic, and Jurassic. Pre-Devonian rocks are exposed on all ranges except the Norquay-Sulphur-Goat Range; there the Devonian Fairholme group forms the hanging wall of the Sulphur fault, and the foot wall rocks are overturned quartzites of the Rocky Mountain group and not the hitherto reported Ordovician Mt. Wilson quartzite. Middle and Upper Cambrian formations on the Rundle and Sawback Ranges have previously been described; the author recognizes five mappable Upper Cambrian rock units in the Sawback-Bourgeau Range and refers to them by letters A, B, C, D, and E, abeyant to future unravelling of Upper Cambrian statigraphy and nomenclature in Main Ranges type sections.

Upper Devonian formations increase in thickness westward. The Fairholme group is in carbonate facies in the Cascade-Rundle Range, the Norquay-Sulphur Range, the Sawback Range and the north end of the Bourgeau Range. South of Mt. Allenby the Fairholme group becomes shaly and the Alexo formation loses a thick middle carbonate member to become a uniform succession of quartzitic siltstones and silty dolomites. A similar succession occurs in the Pilot-Fatigue Range.

The Alexo formation thickens to 400 feet in the west and is composed of dolomite, fine quartzites, and silty dolomites. The Palliser formation thickens to 1,850 feet in the westernmost Front Range.

Mississipppian rocks thicken westward; the Exshaw formation may reach 70 feet. The lower Banff formation contains much black shale and chert. Permian and Triassic rocks are present on back slopes of all ranges except the Pilot-Fatigue Range. Jurassic rocks occur in the upper Spray River Valley on the lower back slope of Goat Range.

Introduction

No valley in the Canadian Rocky Mountains has been traversed or viewed by more geologists than the valley of Bow River. Yet remarkably little has been written about its geology. Apart from early reconnaissance observations, some generalized cross-sections, and localized details, only two publications (Warren, 1927; Clark, 1949) systematically describe geology of Front Ranges along Bow River; a third (North and Henderson, 1954) includes a succinct outline of the structural setting of the area through which Bow River flows, and records observations of the geology in outcrops exposed along the highway which follows the valley. Beyond what is immediately visible from the valley, even less is accounted for in geological literature.

The following paragraphs record the structure and stratigraphy of those western Front Ranges that lie between the Fairholme (easternmost Front Range) and the Main Ranges, along and south of Bow River. The eastern limit of the area concerned is thus marked by the Rundle fault (Clark, 1949), and the western limit is arbitrarily drawn at the Castle Mountain thrust which forms the boundary between Front Range and Main Range structures. The northern limit of observation lies immediately north of Bow River Valley whereas the southern limit is fixed approximately at the Spray Reservoir. With some modification North and Henderson's terminology of the sub-province and its structural units is followed, and thus the area includes the Cascade-Rundle thrust block, the Norquay-Sulphur-Goat (Sulphur-Vermilion Range of Warren) thrust block, and the Sawback-Bourgeau fault block. The latter is a composite and complex structural unit in which North and Henderson include several topographic ranges. One of these forms the west boundary of the area under consideration, and includes Pilot Mountain, Mt. Bourgeau, Fatigue Mountain, and Mt. Nasswald. These peaks lie along the eastern flank of the Main Ranges sub-province and form a distinct range of mountains which the author refers to as the Pilot-Fatigue Range. It is not a separate range in the same sense as other Front Ranges because

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it is not manifested by a thrust fault of proportions equal to them; but in the sense that it is topographically distinct and structurally somewhat different from typical Sawback-Bourgeau structure, it is herein discerned as a separate unit. The ambiguity of considering mountain "ranges" as either geologic or topographic units is well pointed out by such a range as the Pilot-Fatigue Range.

Structure

The Front Ranges constitute a geologic sub-province of the Rocky Mountains lying between the Foothills and Main Ranges sub-provinces, and consist of a series of sub-parallel, west dipping, thrust blocks. The eastern edge of the sub-province is marked by a great thrust, the McConnell fault, which forms the sole fault of the first or Fairholme Range, and which very likely underlies the entire Front Range sub-province. In the immediate vicinity of Bow River at least two lesser faults occur within the Fairholme Range but their geomorphic expression is not particularly distinct; hence the Fairholme Range is topographically one unit but structurally three units. West of the Fairholme Range are four ranges, the eastern three of which, the Cascade-Rundle, the Norquay-Sulphur-Goat, and the Sawback-Bourgeau, are underlain by major thrust faults of magnitude less than that of the McConnell fault. The fourth or westernmost, Pilot-Fatigue Range, although topographically distinct, is a fold structure accompanied by thrusting, and is closely associated with the Sawback-Bourgeau block. Lying on the west slope of the Pilot-Fatigue Range is the Castle Mountain thrust, of magnitude and nature similar to the McConnell fault; this marks the eastern limit of the Main Ranges sub-province. (See Fig. 1, in pocket).

THE CASCADE-RUNDLE FAULT BLOCK

The north end of the Cascade-Rundle fault block is underlain by the Rundle fault which dies out beyond the north end of Cascade Mountain in Cascade Valley. Southward, in the region of the Elbow River headwaters, this fault disappears and displacement along the fault zone is taken up by a second fault, the northern end of which appears first at Three Sisters Mountain where displacement is relatively minor. The latter fault increases in throw southwards until it assumes the total displacement of the Rundle fault zone. Along the entire length of the fault the foot wall rocks are coal-bearing Kootenay strata. According to MacKay (1935) and Clark (1949) a large overturned syncline occurs in the Mesozoic rocks beneath the Mt. Rundle fault in the vicinity of Canmore. The syncline extends southward and is well exposed on the western flank of Mt. Allan where the steep to slightly overturned western limb can be seen. On Cascade Mountain the hanging wall rocks of the fault are either lowermost Palliser or uppermost Fairholme group; the thin bedded and shaly nature of the Alexo formation where it outcrops further south along Mt. Rundle suggests that this formation may well be the locus of the Mt. Rundle fault in the immediate vicinity of Banff. Southward towards Canmore older rocks appear above the fault plane, and for most of the length of Mt. Rundle the hanging wall rocks are Upper Cambrian carbonates. From Three Sisters Mountain southward the hanging wall rocks are Devonian in age, being either upper Fairholme carbonates or the lower part of the Palliser formation. At Kananaskis River the hanging wall of the fault is well up into the Palliser formation.

The geologic section occurring within the Cascade-Rundle block includes Middle and Upper Cambrian, Upper Devonian, Mississippian, Permian, and Triassic rocks. Generally strata dip west 45 degrees to 55 degrees throughout the length of the Range; on the peak of Cascade Mountain the remnant crest of a giant anticline, the east limb of which is absent, may be seen. At the foot of the back slope of the Cascade-Rundle fault block, Upper Palaeozoic and Triassic rocks are deformed into an overturned syncline produced probably by the thrusting action of the succeeding Norquay-Sulphur block. This relatively simple syncline is present in the valley of Spray River between Rundle and Sulphur Mountains but is best displayed on the eastern slopes of Mt. Norquay where several minor folds involving Triassic, Permian, and Mississippian beds are present within the syncline. Deformed Triassic shales and shaly limestones are well exposed in road cuts of the Norquay chair lift road. Vertical to overturned Permian and upper Rundle rocks forming the west limb of the syncline are best seen in the new road cut exposed on Highway 1 immediately west of the Timberline Hotel; they are part of the foot wall rocks of the Sulphur-Norquay thrust fault.

THE NORQUAY-SULPHUR-GOAT FAULT BLOCK

Mt. Norquay and Sulphur Mountain are underlain by a fault or fault zone which southward underlies the Goat Range and the Kananaskis Range and then dies out in the region of Kananaskis Lakes, but which northward continues at least as far as the North Saskatchewan River. Except

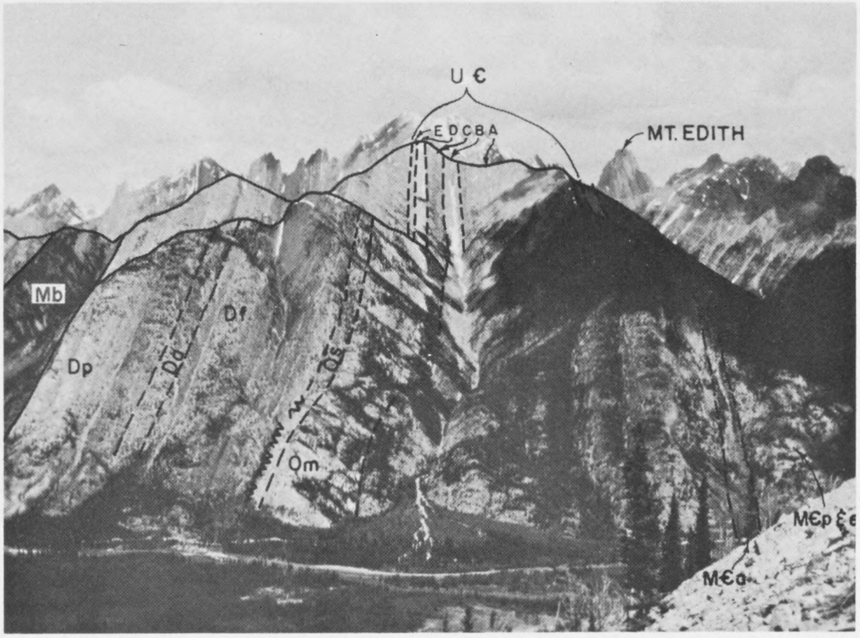
in the Kananaskis Range where relatively broad folding has produced a variety of attitudes, the beds within the block dip west 45 degrees to 55 degrees. A characteristic structural feature of the Norquay-Sulphur block is a tight, anticlinal, north-plunging drag fold overturned along most of the eastern margin of the block immediately above the fault plane. Near Banff the anticline is not evident, but southward along Goat Creek and the western shore of Spray Reservoir it is well displayed, and can best be seen looking north across the Reservoir from the foot of Mt. Buller. At Mt. Norquay the thrust is complicated by several small faults which bring distorted wedges of Banff and Rundle rocks between the hanging wall Devonian section and the foot wall Rocky Mountain group. Warren's map (1927) shows the location of these faults as well as the minor folds in the overturned syncline which forms the valley between Mt. Norquay and Cascade Mountain. The writer agrees essentially with Warren's interpretation of the structure at this locality with the exception of the proposed transverse fault running through the Vermilion Lakes; little to no evidence exists for the latter fault. Throughout the length of the Range the foot wall rocks underlying the Norquay-Sulphur fault are either Triassic or Permian, whereas the hanging wall rocks are Devonian, being the Fairholme group on Mt. Norquay and Sulphur Mountain, and the Alexo formation at the south end of Goat Range. Rocks older than Devonian are not present in this thrust block. deWit and McLaren (1950) state that the Devonian succession on Sulphur Mountain is underlain by the Mt. Wilson quartzite, of Ordovician age. On Sulphur Mountain the hanging wall rocks of the Sulphur fault are Devonian, and the foot wall rocks are quartzites, dolomitic quartzites, and arenaceous dolomites having the same attitude as the overlying Devonian succession. But they indeed are not Mt. Wilson quartzite. They are part of the overturned west limb of the aforementioned syncline underlying Spray River Valley and are strata belonging to the Rocky Mountain group. Petrographic thin-sections of Rocky Mountain quartzites exposed in Highway 1 roadcuts on Mt. Norquay are identical to those cut from rocks forming the foot wall of the Sulphur fault in the gully immediately south of the Upper Hot Springs. The structure is thus a simple one, and there is no necessity to postulate an erosional high in the sub-Devonian unconformity at this locale.

The stratigraphic section in the Norquay-Sulphur block consists of Devonian, Mississippian, Permian, Triassic, and Jurassic beds. The Range is capped by the Rundle group; Permian and Mesozoic rocks lie along the back slopes of the Range and the most complete exposures of the Mesozoic section underlie the broad valley of Sundance Creek and upper Spray River.

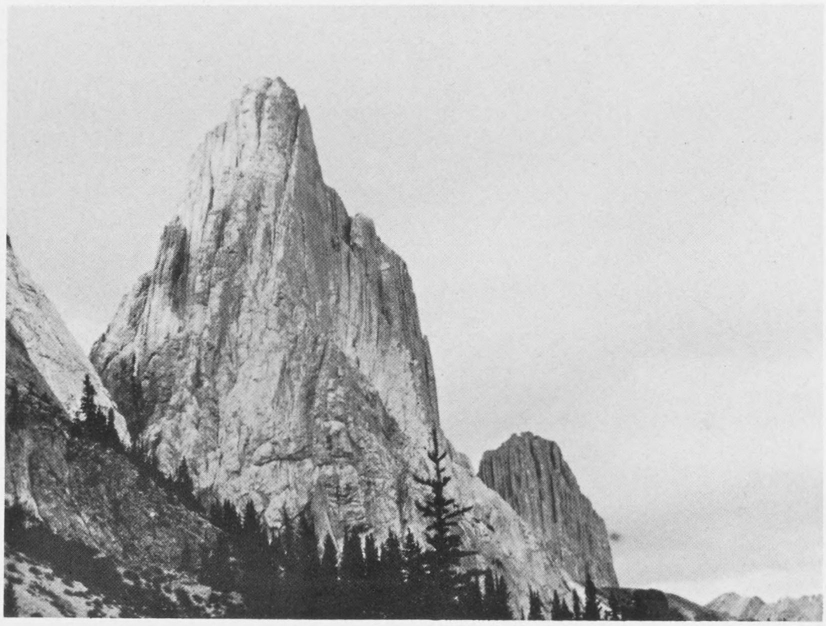
THE SAWBACK-BOURGEAU FAULT BLOCK

The Sawback-Bourgeau fault block is unique among Front Range thrusts by virtue of the complex fault zone underlying it, by its steep west dip, and by the extensive Lower Palaeozoic section exposed in it. North of Bow River, along the headwaters of Forty Mile Creek, the fault zone contains at least five discernible faults; two of these, accompanied by two lesser faults, are evident in the exposures at the southern tip of Sawback Range immediately above Highway 1A. The fault slice containing the vertical spire of Mt. Edith (Palliser formation) lies between these two faults (Pl. I.B). This upturned Devonian section in turn is underlain to the east by faulted Mississippian rocks, the entire zone representing the sheared and overturned western limb of a syncline, the axis of which lies along the valley of Forty Mile Creek; the fault zone is not well exposed south of Bow River due to heavy forest cover along the west side of Sundance Creek Valley. Bedding plane faults in the Cambrian, Ordovician, and Devonian section are apparent at several points along the Bourgeau Range however, and at the extreme southern end of the Range, at Turbulent Mountain, the complexity of the sole fault zone again becomes manifest. The latter mountain is a distorted and sheared, synclinally-folded wedge of Devonian and Mississippian strata lying between Goat and Bourgeau Range proper. Turbulent Creek Valley, separating Turbulent Mountain from the Mt. Allenby-Cone ridge, is an eroded south-plunging anticline which is faulted along its crest on the east shoulder of Cone Mountain. Further south, and beyond the area under consideration, the Bourgeau fault zone over-rides the Sulphur-Goat-Kananaskis block and in this region the Bourgeau Range forms the third Front Range.

North of Bow River the Sawback Range is followed on the west by a broad north-plunging syncline, the axis of which roughly parallels Johnson Creek Valley and the west limb of which is vertical to overturned and sheared off by the Castle Mountain thrust. The axis of the syncline extends southward along Brewster Creek Valley which serves to separate the Pilot-Fatigue Range from the Bourgeau Range, and from whence is derived the name "Brewster Creek syncline." Southward from Mt. Allenby (Pl. II.A) the limbs of the syncline become steeper until at Cone Mountain the western limb is overturned to the east. The northward plunge of the syncline is reversed immediately east and in front of Mt. Turner.



A. South end of Sawback Range. Mb, Banff formation; Dp, Palliser formation; Da, Alexo formation; Df, Fairholme group; Os, Sarbach formation; Om, Mons formation; UC (A to E) Upper Cambrian rocks; MCa, Middle Cambrian Arctomys formation; MC p&e, Pika and Eldon formations.



B. Mt. Edith, Sawback Range. Vertical spire of Palliser formation within Sawback-Bourgeau fault zone. Top of formation to the right.

PLATE I

The stratigraphy of the Sawback-Bourgeau block includes upper Middle Cambrian, Upper Cambrian, Lower Ordovician, Upper Devonian, Mississippian, Permian, Triassic, and Jurassic rocks. The Palaeozoic succession alone totals 12,000 feet of which close to 3,900 feet of Cambrian and Ordovician rocks constitute the thickest pre-Devonian section within the Front Ranges sub-province along Bow River. The most accessible exposures of Palaeozoic rocks can be studied where the Bow Valley separates the Sawback and Bourgeau Ranges. Although the Eldon formation at the base of the section is sheared and distorted, almost complete exposure of the Cambrian-Ordovician section is available at the south end of Sawback Range (Pl. I.A). Contact here with the Devonian is faulted immediately above Highway 1A, but northward along strike the fault moves stratigraphically downwards and a more complete Fairholme sequence is available. The Upper Devonian succession is best exposed and most complete on the north end of Bourgeau Range where it measures 3,443 feet, including 87 feet of "basal Devonian" beds. Identified Devonian and Ordovician rocks at this locality are separated by a zone, 30 feet thick, containing very coarse-grained quartz sandstone. Mississippian and Permian rocks are well exposed, although often difficult of access, along the Range. Tributaries flowing into Brewster Creek from the steep back slope of the Bourgeau Range are very precipitous; the first such tributary entering Brewster Creek upstream from Healy Creek affords moderately good exposures. Better ones may be seen in tributaries along the west slope of the Sawback Range between Mt. Cory and Mt. Ishbel. Mesozoic rocks are also best exposed north of Bow River in the valley of Johnson Creek. Here rocks as young as Jurassic may be present; meagre exposures of them are to be seen along Highway 1A. Brewster Creek Valley contains crumpled shales, siltstones, and thin carbonates of the Triassic.

THE PILOT-FATIGUE RANGE

Although it forms the eastern flank of the Continental Divide from Pilot Mountain south to Palliser Pass, the Pilot-Fatigue block is essentially part of the Front Ranges sub-province and is herein, if somewhat artificially, considered as the fifth and westernmost of the Front Ranges. The artificiality of such a subdivision lies in the fact that whereas at its north end the Pilot-Fatigue block is topographically separated from the Bourgeau Range by Brewster Creek Valley, it is not underlain by a thrust fault of major proportions but is closely associated with Bourgeau structure. Nevertheless its physiographic distinction seems to warrant it being considered as a separate range. As such, it involves a southward tapering strip of mountains and plateaux stretching from Bow River in the northwest to Palliser Pass in the southeast. At its northern end is a quartet of mountains, Mt. Brett, Mt. Bourgeau, Pilot Mountain and Massive Mountain, bounded on the northeast by Bow River and on the southwest by the Castle Mountain thrust which follows a line approximately coinciding with the easternmost major tributary of Red Earth Creek. From Healy Creek southeastwards to Mt. Allenby the eastern limit of the Range is marked by Brewster Creek, whereas on the west the trace of the Castle Mountain thrust follows the two main branches of Simpson River and the east side of Simpson Ridge, thence through Wonder Pass. Southeastwards from Wonder Pass the Castle Mountain thrust passes behind Mt. Byng (west of Turner Mountain) and ultimately over-rides the Spray Mountains (the southern extension of Sawback-Bourgeau and Pilot-Fatigue structural units) at Palliser Pass.[2]

The Pilot-Fatique Range is essentially a fold range containing one persistent thrust fault located about midway the breadth of the Range and extending its full length. The trace of this thrust, named the Fatigue fault, is an almost straight line striking north 150 degrees east from the northeast face of Pilot Mountain to the saddle between Mt. Sir Douglas and Mt. Williams immediately east of Palliser Pass. Stratigraphic throw along the thrust is not uniform; the foot wall rocks are almost everywhere Rundle, but the hanging wall rocks vary from the Lower Ordovician Sarbach formation to Upper Devonian Palliser formation. In the north, the foot wall of the fault is the west limb of the Brewster Creek syncline, which is here crumpled into a further anticline-syncline sequence. In the south, along Bryant Creek Valley, several other sizable folds occur in Mississippian and Devonian strata immediately east of the Fatigue fault. Drag folding in the hanging wall rocks immediately adjacent to the fault is apparent along much of its length, but probably most apparent in the Pilot Mountain region where the axis of a large anticline nearly coincides with the fault. The flaring west limb of the anticline may be seen in Pilot Mountain and Mt. Bourgeau, whereas the east limb constitutes the steeply east-dipping strata on the east flank of those mountains.

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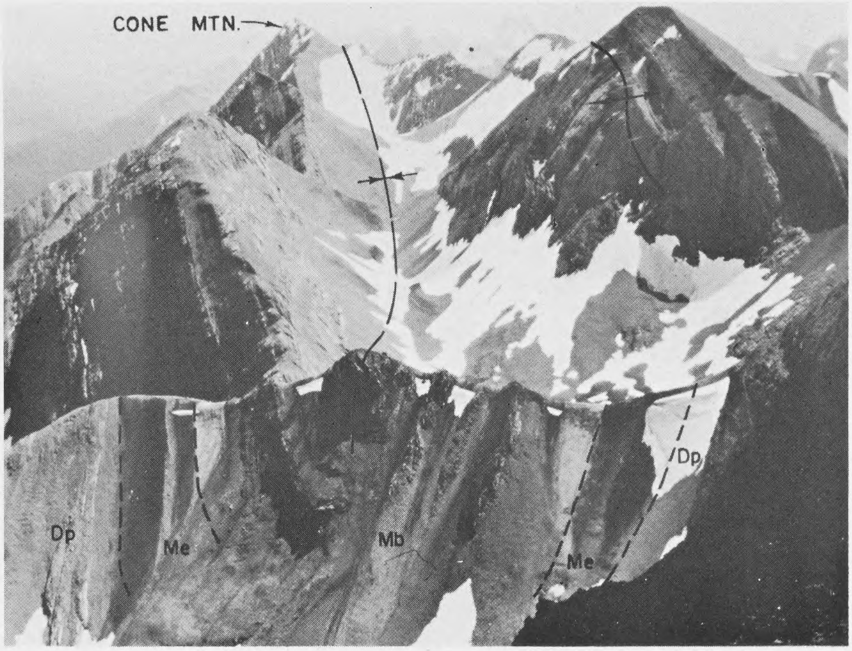
2 Recent personal communication with W. C. Gussow leads the author to believe that the locus of the Castle Mountain thrust as presently shown on Figure I is in error and that it follows, rather, the base of the Assiniboine massif thence along Surprise Creek Valley to Eohippus Lake and north along the upper east flank of the ridge between Pharoah Creek and Mt. Brett.



A. Axis of Brewster Creek syncline immediately south of Mt. Allenby. Adjoining anticline on west flank of Bourgeau Range. Cone Mountain at south end of Range. Mb, Banff formation; Me, Exshaw formation; Dp, Palliser formation.

B. Gibraltar Rock. Recumbent anticline in Devonian rocks. Dp. Palliser formation; Da, Alexo formation; Dmh & px, Mount Hawk and Perdrix formations.

PLATE II

The back slope of the Fatigue thrust block forms the foot wall for the massive Castle Mountain thrust. The latter is clearly exposed in Wonder Pass on the north side of Marvel Lake and at numerous points southeast of here along the strike of the fault. The Hector formation everywhere in the area occupies the hanging wall of the Castle Mountain thrust. North of Mt. Assiniboine the thrust plane is obscured in karst topography of the Valley of the Rocks, and by an ancient but enormous landslide in Golden Valley. Simpson River Valley forms a marked topographic depression along the locus of the fault between Simpson Ridge and Sunshine Plateau. Citadel Peak is a triangular klippe of nearly horizontal Hector quartzites resting atop the back slope of the Fatigue thrust block, separated from the main Cambrian massif of Simpson Ridge. The fault contact can again be seen west of Sunshine Lodge and from here northwestward it is believed to lie in the valley of the large tributary flowing into Red Earth Creek from the south along the west side of Mt. Brett.

Although the Castle Mountain thrust cannot thus be clearly seen everywhere along its length in the area under concern, the results of its movement are in many places clearly and strikingly visible. The main effect it had on the "trailing edge" of the Fatigue fault block was enormous drag which folded the Ordovician and Devonian strata of that block into a syncline, the western limb of which is overturned to the east (Fig. 1.A). In places, such as at Quartz Hill, the overturn is completely recumbent, and the Mons and Sarbach formations lie horizontally and upside-down above the Devonian. On the back slope of Nasswald Peak between Nasswald and Fatigue Pass a small-scale but distinctive example of a first-order nappe is displayed. Here the syncline on the rear edge of the Fatigue block is superimposed by a recumbent anticline in the form of a Z-shaped fold in which thrusting has occurred in the middle part of the overturned limb. The top half of the Z-fold (the normal limb) and the vertical nose (or brow) have been carried forward along the thrust and left respectively as west-dipping and vertical Ordovician strata atop the gently west-dipping Palliser formation that forms Nasswald Peak. A further and striking manifestation of the Castle Mountain thrust may be seen immediately west of Sunshine Lodge where Hector quartzites rest horizontally on the vertically upturned edges of the Ordovician formations. Excellent exposures show the Hector, underlain by a brown schistose slate of unknown age (possibly a thick mylonite), outcropping west of a well-marked line which is the trace of the Castle Mountain fault. The edge of the thrust sheet has been eroded back revealing the upturned, fractured, calcite-veined, sheared ends of Sarbach strata. The topography is flat and the cover thin; in walking across the area one is essentially walking across the plane of the Castle Mountain thrust. It is an impressive experience.

Whenever the Castle Mountain thrust can be observed, as for instance in the Sunshine Plateau area, it is a low-angled thrust fault, the plane of which is broadly and gently curved. At Citadel Peak the fault plane lies at a higher elevation than the base of Simpson Ridge; remnants of dragged Ordovician strata on the high back slope of Fatigue Mountain and Nasswald Peak in turn stand higher than the base of Citadel Mountain. In the Assiniboine massif little deformation in the hanging wall is visible and the thick Cambrian succession lies horizontally, or nearly so, to the very edge of the fault trace. For its magnitude the fault plane is remarkably sharp and free of gouge. Where it is seen at Citadel Mountain, and west of Sunshine Lodge, the Hector formation, a massive succession of fine to coarse grained, crossbedded orthoquartzites with conglomerates, siltstones, and shales, is underlain by a varying thickness of dark brown to sepia colored, micaceous, schistose, soft slate. The age and identification of these slates has not been determined and they may well represent a thick mylonite lying along the fault plane. A noteworthy feature of some of the lower granule and pebble conglomerates of the Hector is the presence of muscovite and coarse feldspar fragments; in places the rudites are feldspathic conglomerates.

Rocks in the Pilot-Fatigue Range include Lower Ordovician, Upper Devonian, and Mississippian strata. The Ordovician Mons and Sarbach formations are exposed as hanging wall rocks of the Fatigue fault between Nasswald Peak and Healy Creek; they also occur along the length of the extreme western side of the Range where they stand vertically to overturned. The putty-grey limy shales, thin to medium bedded argillaceous limestones, and limestone pebble conglomerates of the Mons formation, with an estimated thickness of 1,000 feet, are overlain by nodular, dense, massive, siliceous limestone and massive to thick bedded, ochre to buff weathering dolomites of the Sarbach formation; the latter has a thickness in excess of 450 feet, a considerable increase over its thickness on the Bourgeau Range. Between the Sarbach and the Fairholme units on Fatigue Mountain, 75 to 80 feet of coarse grained, dolomitic, quartz sandstone occur, in a stratigraphic position similar to those sandstones found on the Bourgeau Range. Devonian rocks form the bulk of the Range and are exposed throughout its length west of the Fatigue fault, where the Palliser formation caps

TABLE I

Series	Stage	ROCK UNITS	Rundle Rge. deWit (1956)	Rundle Rge. Usher	Sulphur Rge.	Sawback-Bourgeau Rge. deWit (1956)	Sawback-Bourgeau Rge. Usher	Pilot-Fatigue Rge.	FAUNAL ZONES
L. Ordovician	L. Canadian	Sarbach fm. Limestone - dense, grey, massive, siliceous with black shale interbeds underlain by brown weathering silty dolomites.	* n.p.	n.p.		124	243	450	
		Mons fm. Limestone - putty grey, argillaceous; soft limy shales; limestone pebble conglomerate. Basal 75' brown weathering.	n.p.	n.p.		986	713	1000	Symphysurina fauna 225' above Saukia zone
Upper Cambrian	Trempealeauan	Fm. E. Limestone - thick bedded, fine grained, with orange weathering silt stringers. Collenia colonies.			Pre-Devonian rocks not present	Unnamed fm. 400'; Lyell or Ottertail fm. 1470'; Bosworth fm. 165'	15	Cambrian rocks not exposed	Saukia fauna 25' above top of Fm. E.
		Fm. D. Shale, siltstone - thin bedded, laminated, interbedded with limestone; unit weathers dark rusty brown. Intraformational breccia of silty limestone.					85		
		Fm. C. Limestone - massive, dark grey, calcarenite, argillaceous; with thin interbeds of intraformational limestone pebble conglomerate.					95		
	Franconian	Fm. B. Shale - green brown, orange weathering; with medium to thick bedded fossiliferous calcarenites and some orange weathering argillaceous siltstone.					225		Dikelocephalus postrectus fauna Briscoia fauna
	Dresbachian	Fm. A. 793' - Dolomite - thick and well bedded, finely crystalline, pale grey; with cryptocrystalline, argillaceous limestone. 225' - Dolomite - massive, coarsely crystalline, mottled grey, white, pink. 357' - Limestone - medium to thick bedded, argillaceous; with shale, siltstone, oolitic limestone, sideritic nodules.	313	322			1375		Cedaria fauna
		Arctomys fm.	188	164		209	201		
M. Cambrian		Pika fm.	150	115		+175	137		Thomsonaspis fauna
		Eldon fm.					797		

* n.p. - NOT PRESENT

some of the highest peaks. Several features distinguish the Devonian sequence in the Pilot-Fatigue Range; the Fairholme group is of a shaly nature; the Alexo formation is abnormally thick and of a highly quartzitic nature; the Palliser formation has a thickness almost double that of other Front Ranges in this area. Mississippian rocks, much distorted by folds and faults, form the foot wall rocks of the Fatigue fault and the east slope of the Pilot-Fatigue Range. The most accessible and least deformed section east of the fault lies north of the approaches to Allenby Pass. This section may include a few tens of feet of the Rocky Mountain group. West of the fault, and excepting on Pilot Mountain and Mt. Bourgeau where fairly complete but rather inaccessible sections of the Banff and Rundle are present, only remnants of the Banff or Banff and Rundle are present on the back slope of the Range, notably at Sunshine Plateau and Gibraltar Peak. Mesozoic rocks are non-existent in the Range.

Stratigraphy

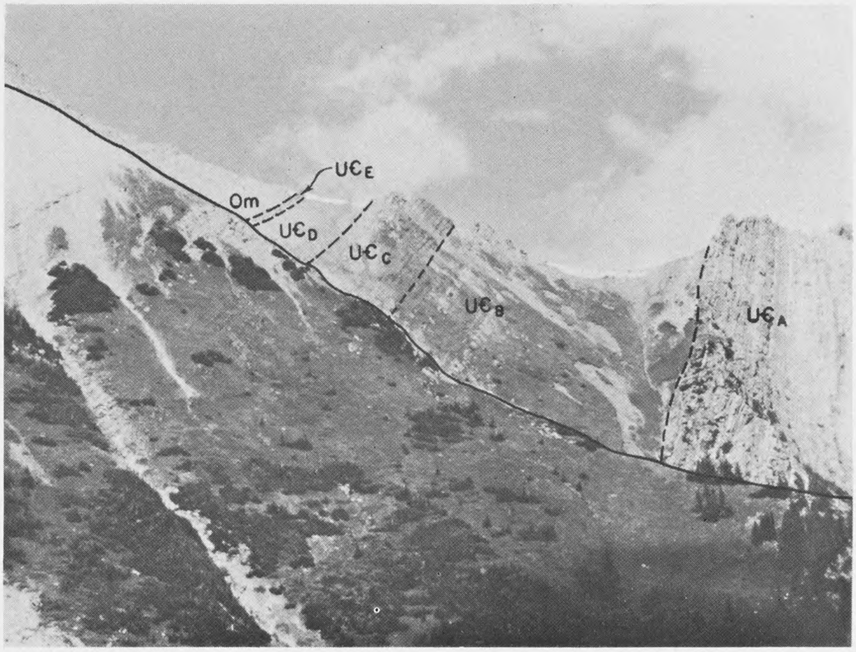
Cambrian and Ordovician

The oldest rocks in the Front Ranges along Bow River Valley are upper Middle Cambrian; they outcrop as hanging wall rocks above the McConnell fault, the Rundle fault, and the Sawback-Bourgeau fault, (Table I.) In the Fairholme Range they are succeeded by a few score feet of lowermost Upper Cambrian strata, in turn by Devonian strata. In the Rundle Range a much thicker remnant of Upper Cambrian lies between the Middle Cambrian hanging wall rocks and the Devonian succession. No pre-Devonian rocks are exposed on the Sulphur-Norquay block. In the Sawback-Bourgeau Range, a complete Upper Cambrian section, surmounted by Lower Ordovician rocks, underlies the Devonian sequence and rests upon the Middle Cambrian.

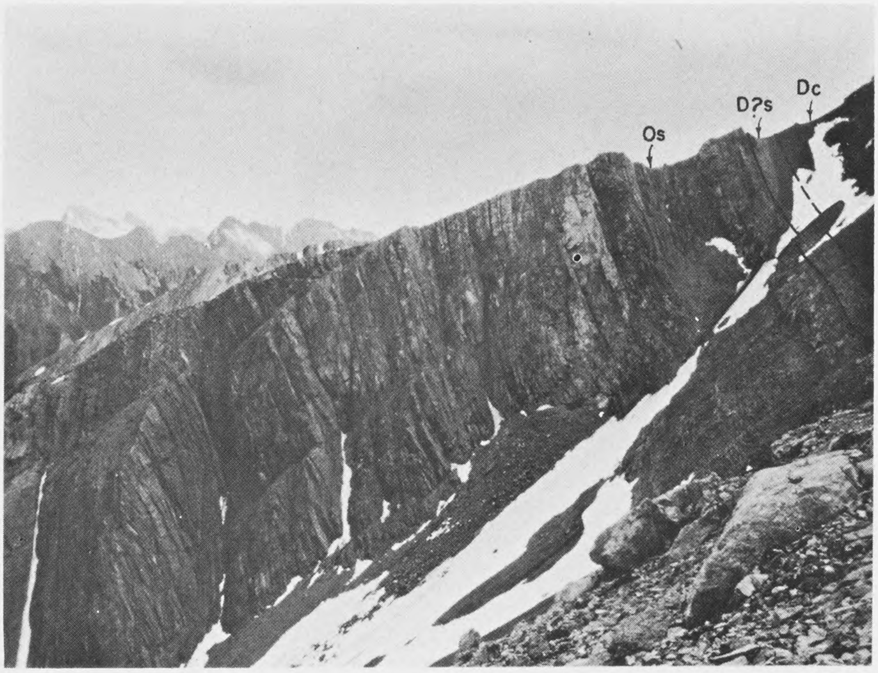
Through the work of Deiss (1940) and Rasetti (1951) in the Main Ranges, Middle Cambrian stratigraphy is well established and the rocks of that age are readily recognized on lithological and faunal grounds. In particular the massive Eldon formation, underlain and overlain respectively by the fossiliferous Stephen and Pika strata, serves as a distinctive mapping unit in the Front Ranges. Unhappily, Upper Cambrian geology is not so well known, and the nomenclature for rocks of this age is presently in a state of flux. Walcott (1928) described several Upper Cambrian sections within the Main Ranges, and little has been done on these rocks since Walcott's time. A confusion in Upper Cambrian stratigraphic terminology arises because of the several sections which he measured, each with its singular nomenclature, and the relationship among these areally separated sections remains obscure. Undoubtedly lithofacies variations are much responsible for uncertainty in the nomenclature, as is witnessed by the lithological differences in the Mt. Bosworth, Glacier Lake, and Ottertail Range Upper Cambrian exposures. Despite the lithofacies distinct faunal zones can be recognized and we must ultimately turn to paleontological evidence for resolution of the confusion. It is, therefore, in this author's opinion, unwise to apply formation names to Upper Cambrian exposures in the Front Ranges until a more thorough knowledge of Main Range geology is known. Thus, although the Upper Cambrian rock units in the Rundle and Sawback-Bourgeau Ranges have been recognized and named by earlier authors (deWit, 1956), and although essentially the same rock units were independently distinguished by the present author, they are herein referred to by symbolic letters rather than by use of the pre-existing nomenclature. Table I illustrates the Cambrian and Ordovician rock units present in the western Front Ranges, their lithology, and the associated faunal zones. It also includes a comparison of deWit's and the author's measured thicknesses on the Rundle and Sawback Ranges.

Within the Upper Cambrian interval the Arctomys formation is readily recognized by virtue of its distinctive lithology, and because it weathers recessively in profile into an orange to rusty coloured notch. The overlying Upper Cambrian rocks are a succession of carbonates and shales, stratigraphically equivalent to the Bosworth, Ottertail, or Sullivan-Lyell intervals of the Main Ranges. The section is well developed on the Sawback-Bourgeau Range where it consists of five units; an upper, a middle, and a lower carbonate separated by two recessively weathering shale units. The five-fold nature of this interval persists from Mt. Allenby as far north along the Sawback Range as Pipestone River (Pl. III.A and B).

The Lower Ordovician Mons formation is well exposed along Highway 1A at the south end of Sawback Range. A better exposure of it is found on the Bourgeau Range (See Fig. 1 for location of Cambrian and Ordovician section) where the formation is divisible into two members; the lower one consists of brown weathering siltstones and silty limestones, and the upper one, making up the bulk of the formation, is putty-grey to white weathering argillaceous limestones and limy shale, with numerous beds of limestone-pebble conglomerate. Only a small part of the Sarbach formation is exposed within the Sawback-Bourgeau Range. It comprises thick bedded,



A. Cambrian-Ordovician contact, Bourgeau Range. Om, Mons formation; UC, (A to E), Upper Cambrian rock units.



B. Ordovician-Devonian contact north end of Bourgeau Range. Dc, Cairn formation; D?s — basal Devonian (?) sands; Os, Sarbach formation.

PLATE III

light grey and brown, grey and rusty weathering dolomite and silty dolomite. The contact between it and the Mons formation is, at a distance, marked by the dark grey to brown and occasionally rusty weathering of the younger formation in contrast to the lighter grey colour of Mons strata. In the Pilot-Fatigue block the Sarbach formation displays 200 feet more strata than are present in the Sawback-Bourgeau Range. These include lower dolomites which are thick to massive bedded and ochre to buff weathering, overlain by nodular, dense, massive, siliceous grey weathering limestone threaded with orange coloured anastomosing silt and argillaceous stringers. Black platy shale zones occur in the uppermost measures of the formation, these may locally be fossiliferous.

DEVONIAN

The reader unfamiliar with the current state of Devonian stratigraphy in the Rocky Mountains of Alberta is referred to the work of McLaren (1953, 1956), McLaren and Belyea (1956, 1957a, 1957b), and Taylor (1957, 1958). Descriptions of Upper Devonian sections in the three easternmost Front Ranges have been made at Loder's Lime Plant (Fairholme Range), Canmore or (erroneously named) Whiteman's Pass (Rundle Range), and Sulphur Mountain (Sulphur Range). In each of these sections the Fairholme group is in carbonate facies. Aside from Devonian sections in the Crowsnest area, and a photograph of Gibraltar Rock (North and Henderson, 1954, p. 33), other published information on Fairholme facies south of the Bow River is not available.

From Mt. Allenby in the Bourgeau-Sawback Range northwards, the Fairholme group consists of the carbonate Southesk and Cairn formations, with recognisable Arcs, Grotto, and Peechee members (Belyea and McLaren, 1957a) in the Southesk interval, (or if Taylor's correlations (1958) are preferred, the Nisku and Leduc formations), and a chert bearing member in the lower Cairn. A short distance south of Mt. Allenby the Fairholme becomes shaly, and thence to Cone Mountain at the south end of the Range, the Fairholme group consists largely of dark shales and shaly carbonates. At Cone Mountain the Cairn formation (including Flume interval) is readily recognisable, but within the overlying shales it is difficult, if not impossible, to distinguish and separate Perdrix and Mount Hawk strata. The base of the Alexo is, on lithological grounds, somewhat arbitrary because the appearance of silt occurs well down in the section and increases gradually upwards to where the defined Alexo consists of a uniform succession of silty quartzitic dolomites and dolomitic quartzitic siltstones, all of uniform outward appearance. A characteristic feature of the shale part of the Fairholme sequence is the orange weathering hue of those carbonate bands which bear silt. This feature is apparent as well throughout the Pilot-Fatigue Range, and coupled with the blackness of the shales and the non-silty carbonates, prompted a field assistant to remark that the Fairholme was in "Hallowe'en mode." In the Pilot-Fatigue Range, the Cairn formation is thicker than on Cone Mountain, and the sequence between the Cairn and Alexo formations is predominantly shales and shaly carbonates; the base of the Alexo continues to be somewhat arbitrary and, in the absence of fossils, will probably remain so. Thus the Fairholme of the Pilot-Fatigue block is characterized by a basal unit of Cairn dolomites overlain by an accumulation of black fissile shales and thin-bedded argillaceous limestones which become silty upwards and, with gradual increase in silt, pass into orange weathering dolomitic quartzitic siltstones of the Alexo formation. The most typical and accessible section is found on the east face of Fatigue Mountain.

In the western Front Ranges the Alexo formation miantains its defined character of a silt-bearing unit lying above the Fairholme group and below the massive cliffs of the Palliser formation. Belyea and McLaren (1956) report 333 feet of Alexo in the Rundle Range, but in view of extensive faulting in upper measures of the formation in this area it is suggested that the true thickness of the formation is considerably less than 300 feet. The writer measured 163 feet of unfaulted Alexo in the Rundle Range above Canmore, which strata were separated from basal Palliser by a 200-foot interval of contorted and partly covered Alexo-like rocks. On the Sawback-Bourgeau Range the Alexo is a tripartite formation consisting of upper and lower quartzitic siltstone and sandstone zones respectively 26 feet and 47 feet thick, separated by a middle massive unit, 200 feet thick, of uniform, clean, massive and well bedded, coarsely-crystalline dolomite, very similar in appearance to Southesk (Peechee) dolomites. On Mt. Allenby the tripartite nature of the formation is still evident, but here the lower silt zone contains thin bands of green silty shale. Southward from here the Alexo passes into a uniform succession of highly silty dolomites and dolomitic, quartzitic siltstones.

Except in the extreme southwestern sector of the area the Palliser formation persists in being the thick, monotonously uniform, cliff-forming unit it is elsewhere in the Front Ranges of the southern Alberta Rocky Mountains. Immediately east of the Castle Mountain thrust in the Assiniboine area the Palliser formation reaches the unusual thickness of nearly 1,850 feet, and is there distinguished by including thin bedded cherty crinoidal limestones in its upper part (Costigan member ?), and having massive nodular limestones low in the formation, as well as two black shaly limestone bands about the middle of the formation.

MISSISSIPPIAN AND PERMIAN

Since Banff is the type area for most of the Mississippian and Permian formations of southwestern Alberta, and since these formations have had previous thorough description, it seems unnecessary to discuss their occurrence on the Rundle and Norquay Ranges. On the Sawback-Bourgeau Range Mississippian rocks form the steep western back slopes of the Range and, as far south as Mt. Allenby, the precipitous serrated crest of the Range; on the west limb of Brewster Creek syncline the dip is more gentle and although the eastern flank of the Pilot-Fatigue Range is dominated by some impressive peaks in the vicinity of Pilot Mountain and Mt. Bourgeau, and Allenby Pass, sections in the latter area are the most accessible. On the Bourgeau Range nearly 3,800 feet of Mississippian rocks were measured and 650 feet of the Rocky Mountain group.

The Exshaw formation in the Bourgeau and Pilot-Fatigue Ranges is somewhat different from that in ranges further east. It is nearly 70 feet thick and consists of the usual black fissile shales which are separated into a lower 40-foot zone and an upper 20-foot zone by an interval, 6 to 10 feet thick, of ochre weathering, argillaceous, highly cherty limestone. An alternative interpretation would be to regard the middle ochre unit as equivalent to the rusty weathering beds at the top of the type Exshaw (Warren, 1937), thus limiting the thickness of the formation in the western ranges to 40 feet.

At Mt. Allenby the Banff formation is less than 1,000 feet thick and its lithology is somewhat different from that further north on the Range. It begins with brown shaly limestone and shale, passing up into black shale and well bedded, thin-bedded, highly cherty limestone. Black shale follows above the cherty limestone and the top of the formation is characterized by medium to thick-bedded limestone with shale interbeds. In the Pilot-Fatigue Range the Banff is exposed in a small remnant on the back slope of Sunday Mountain, and in a much thicker remnant on the back slope of Gibraltar Peak. As on Mt. Allenby it contains a considerable amount of dark black shale and has an extremely abundant development of jet black, thin-bedded chert.

The Rundle formation forms the foot wall rock of the Fatigue fault throughout the length of the fault in the Pilot-Fatigue Range. These beds are generally so distorted as to be unmeasurable. West of the fault the Rundle caps such peaks as Pilot Mountain [3] and Mt. Bourgeau at the north end of the Range but further south only basal Rundle strata are present on mountains such as Wonder Peak. Elsewhere west of the fault rocks younger than the Banff formation are not present.

The Rocky Mountain group is present on the western slopes of the Cascade-Rundle and Norquay-Sulphur Ranges. A particularly good section of it has been freshly exposed on Highway 1 immediately west of Banff on Mt. Norquay. The formation occurs on the west back slope of the Norquay-Sulphur Range; in the east limb of the Brewster Creek syncline along the west flank of the Bourgeau Range the formation is present as far south as Mt. Allenby. Elsewhere along the west margin of the Front Ranges in this area it is not present.

MESOZOIC

No attempt was made to study in detail the Mesozoic units which are present within the area. Triassic rocks occur on the western or back slopes of all of the fault blocks except the Pilot-Fatigue Range, and because they and younger Mesozoic rocks are rather relatively weak formations they tend to underlie the valleys which separate the ranges.

On the back slope of the Norquay-Sulphur-Goat Range Triassic sediments are partly exposed in a new road cut on Highway 1 and at Sundance Canyon; good sections of the formation can be obtained about mid-length of the Goat Range opposite the Warden's fire cabin on Spray River; younger sediments lie atop the Spray River formation here, either part or all of the Fernie formation and possibly, also, strata of Lower Cretaceous age. Fernie shales outcrop along the

3 Permian rocks may cap Pilot Mountain.

southwestern flank of Goat Range in small west-flowing tributary valleys, and in Spray River Valley opposite the northeast shoulder of Mt. Turbulent. On the Sawback-Bourgeau Range the most complete exposures of Mesozoic rocks are to be found west of the Sawback Range in the northern extension of Brewster Creek syncline exposed along Johnson Creek Valley; they can be seen in rather poor road outcrops along Highway 1A. In the southward continuation of the syncline poor exposures of Spray River formation occur along the bottom of the northern end of Brewster Creek Valley. Elsewhere in the Sawback-Bourgeau and Pilot-Fatigue Ranges, Mesozoic rocks are absent; nor do they appear along Bow River Valley west of the Castle Mountain thrust.

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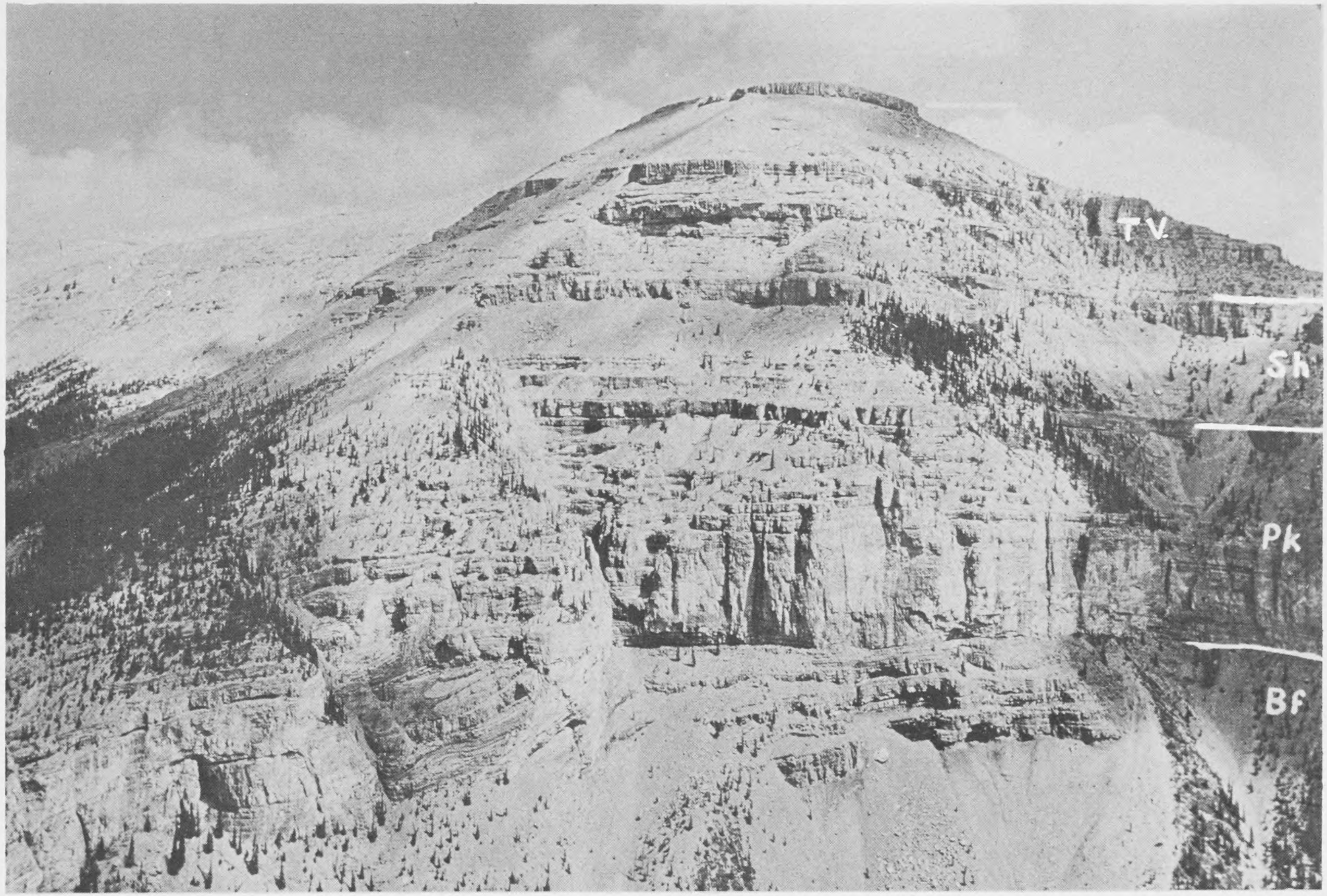

Mississippian outcrops on south face of un-named mountain two miles southeast of peak of Moose Mtn
TV — Turner Valley; Sh — Shunda; Pk — Pekisko; Bf — Banff.

PLATE IV

CYCLIC CARBONATE SEDIMENTATION IN THE MISSISSIPPIAN AT MOOSE DOME, SOUTHWEST ALBERTA [1]

L. V. ILLING [2]

ABSTRACT

The Mississippian seas covering Western Canada shallowed northeastwards towards a shoreline on the Canadian Shield and deepened southwestwards to the present Cordilleran area. Various types of limestone, controlled in the main by depth of water and the degree of contamination by terrigenous sediment, were formed in belts across this shelving epicontinental sea. Changes in sea level caused these belts to move back and forth. The genesis and diagenesis of the resulting cyclic sequence of limestones and dolomites are discussed in terms of the typical succession exposed in the Moose Dome inlier of the Foothills of southern Alberta.

The Banff formation at the base consists predominantly of argillaceous, cherty, pasty limestones formed by the anaerobic rotting of skeletal detritus below wave base. Bioclastic lime-sandstones (Pekisko formation) appeared as the seas shallowed, first with interstitial pasty matrix and then clean-washed as the energy of the depositional environment increased. Thin oolitic beds are the first sign of increased salinities. Continued shallowing segmented the seas into lagoons where lime-muds were precipitated to form the lithographic limestones of the Shunda formation. Associated dolomite-muds accumulated in local, more saline lagoons.

A return to open shelf conditions started the second cycle with the deposition of clean-washed lime-sands (Turner Valley formation) composed predominantly of crinoid ossicles and bryozoan fragments. Reservoir rocks of porous and permeable dolomite are common in these sediments, particularly those formed from the more heterogeneous bioclastic detritus. The dolomitization is believed to be epigenetic, — formed during a late phase of diagenesis.

Cryptocrystalline dolomites, brecciated by the solution of associated anhydrite, occur in the overlying Mount Head formation, which represents the evaporitic phase of the second cycle.

INTRODUCTION

Moose Dome is one of the larger tectonic culminations in the Foothills of southwest Alberta, situated five miles east of the Front Ranges of the Rocky Mountains and approximately thirty miles west of Calgary (Fig. 1). The Mississippian inlier is dissected by the valley and tributaries of Canyon Creek, a superimposed stream that was established on the Mesozoic cover which has since been stripped off. Access to the inlier is relatively easy via Canyon Creek from its junction with the Elbow River, or via the Moose Mountain fire tower trail.

The area was mapped by Beach, who published structural cross-sections (1943, map 688A) and a measured section of the Mississippian (ibid, pp. 19-20, 27-28). A summarized sequence and discussion of the Mississippian stratigraphy was presented by Douglas (1953, pp. 79-83).

Approximately 1600 feet of Mississippian strata are exposed in the inlier, divisible into Mt. Head, Turner Valley, Shunda, Pekisko and Banff formations (Plate IV), the same units that are recognized in the subsurface to the east (Fig. 2). The lower part of the Banff and the Exshaw formation are not exposed but were encountered in the several unsuccessful exploratory wells drilled on the structure (MacNeil, 1934).

This paper is an attempt to interpret the genesis and diagenesis of these Mississippian strata. In so doing, a relatively simple cycle of carbonate sedimentation is presented which is believed to be of wide application.

REGIONAL SETTING

During late Devonian time most of the western Canadian plains area was covered by a shallow sea in which carbonate deposition (Palliser and Wabamun formations) was taking place. Because of its great extent and shallowness, slight changes in sea level or climate had far-reaching effects. The black spore-bearing radioactive shales of the Exshaw and Bakken formations were probably the result of such an adjustment. A period of slight uplift of the Canadian Shield, coupled with very gentle warping and local erosion on the plains, segmented the area into huge lagoons into which the new pattern of sluggish marine currents brought only the finest of terrigenous clastics to form euxinic shales.

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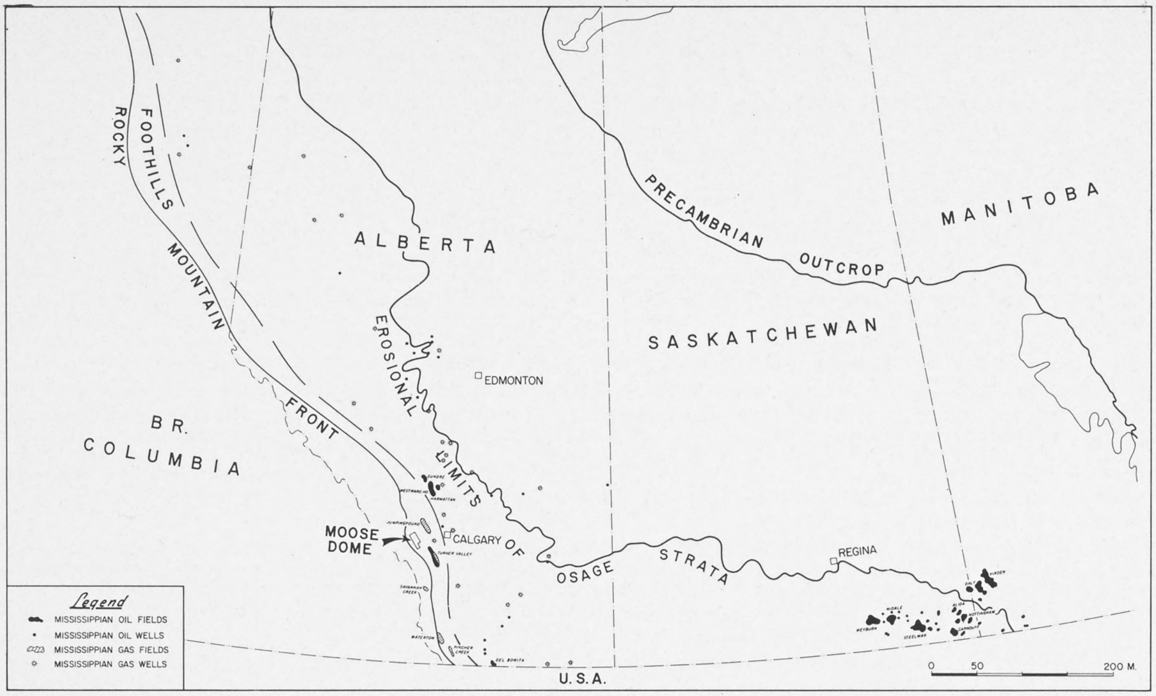
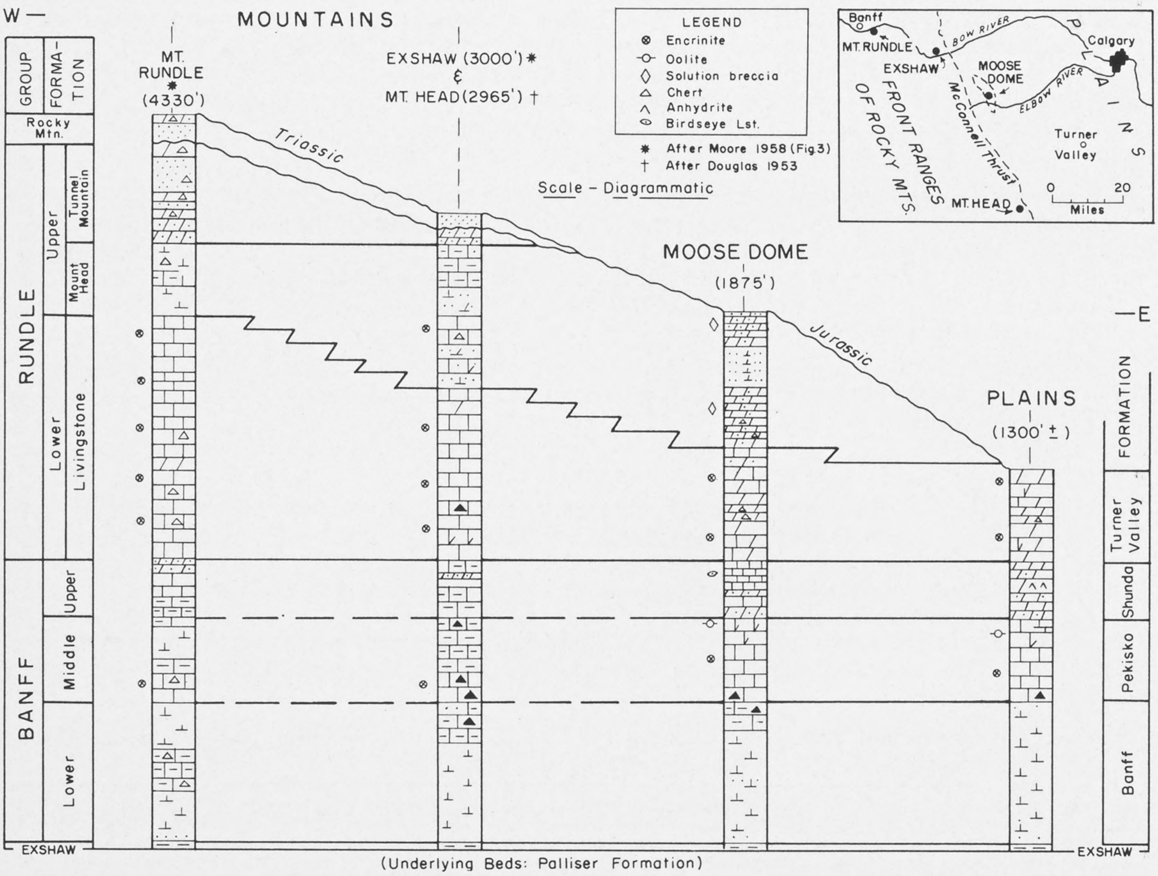
1 This paper is part of a longer article presented at the Fifth World Petroleum Congress in New York, June 1959, entitled "Deposition and diagenesis of some Upper Palaeozoic carbonate sediments in Western Canada".
The results here summarized were formulated during studies for Shell Oil Company, whose permission to publish this material is gratefully acknowledged. Thanks are extended to G. V. Middleton of McMaster University who made the field studies of the Moose Dome inlier, and collected the samples on which my investigations have been based; also to the many colleagues who have read and criticized the manuscript.

2 Consultant geologist to Shell Oil Company of Canada, Limited, Calgary.



Oil and gas discoveries in Mississippian carbonate sediments of Western Canada, (January 1958). FIGURE 1



Correlation of the Mississippian succession at Moose Dome with the Front Ranges of the Rocky Mountains and the Southern Alberta Plains. FIGURE 2

This event began the Mississippian cycle of sedimentation. Subsidence followed, restoring marine circulation and leading to the deposition of argillaceous limestones. These constitute the Banff and Lodgepole formations. After this initial transgressive phase, the general story of Mississippian sedimentation is one of major regression, on which several smaller transgressions and regressions are superimposed, giving the sequence a marked cyclicity.

On a regional scale the Mississippian seas shallowed eastwards and north-eastwards towards the Canadian Shield, which was probably partly emergent, though of low relief. Towards the west and southwest the seas deepened and sediments were deposited below wave base. A series of crudely concentric belts of differing but related facies developed on this gently inclined epicontinental shelf, and these belts tended to migrate to and from the shield in response to the cyclical changes in the strand line.

There are at least three main sedimentary cycles in the Mississippian of Alberta. At Moose Dome, only the first two are represented, later units having been eroded away. This is illustrated in Figure 3b, in which the environmental phases correspond with those shown in the idealized cycle of Figure 3a. The latter outlines the expected changes in carbonate sediments caused by a progressive shallowing from a marine environment below wave base (bottom of diagram), through shallow marine, to lagoonal conditions (top of diagram).

Moose Dome Succession

A log of one of the sections exposed at Moose Dome is shown in summarized form in Figure 4.

BANFF FORMATION

The Banff formation consists predominantly of limy and silty shales and argillaceous cherty limestones formed from a lime-paste with scattered fossils and fossil relics.[3] This type of carbonate sediment, which falls within the wide category of "normal marine limestone" of Krumbein and Sloss (1953, p. 137), formed in an open marine environment where bottom conditions were anaerobic. Singly or in combination, two factors controlled this condition: either the sea bed was below wave base (phase A of Figure 3), and/or there was an abundance of argillaceous sediment (implying an absence of strong marine currents). It is believed that the first was the dominant factor, but the influence of argillaceous pollution in creating anaerobic bottom conditions is also evident. The resulting decay of entombed organic tissues led to rotting and disintegration of the skeletal structures around them and produced a pasty lime-matrix (now a sub-lithographic limestone) in which only the larger and more resistant skeletal fragments can be distinguished (Pl.I.1). Ammonia would be a likely by-product of the organic decay and the resulting alkaline conditions may have contributed to the lime-paste by inducing precipitation.

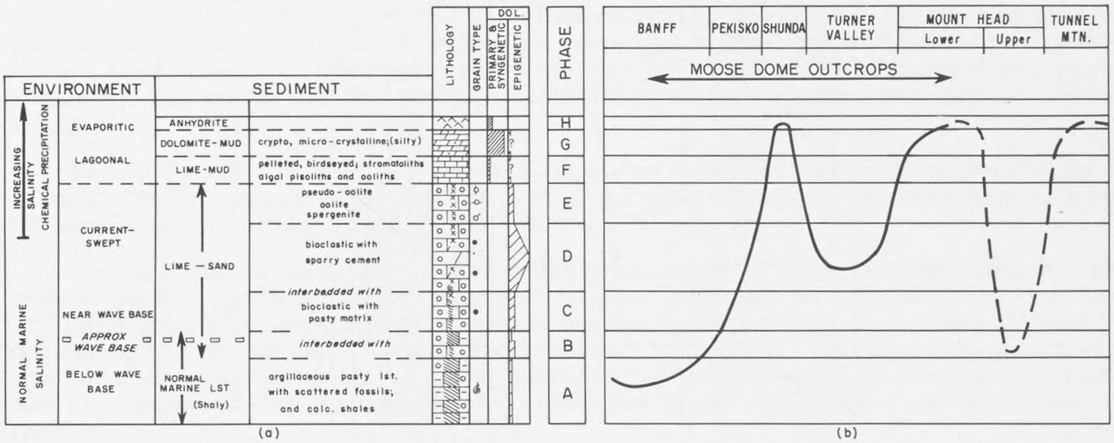


FIGURE 3

Carbonate sedimentation cycle: (a) General, (b) Applied to the Mississippian at Moose Done. (See legend of Fig. 4.)

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3 Since this paper was prepared, a valuable classification of limestones has been published by R. L. Folk (1959). Many of the rock types named and discussed by Folk in his comprehensive treatment will be recognized in the present paper. Being more limited in scope, and being more concerned with genesis than nomenclature, a somewhat different emphasis and grouping will, however, be apparent. In particular, an attempt is here made to distinguish between such genetically different rocks as lithographic precipitated lime-mudstones and sub-lithographic pasty limestones formed of macerated ill-sorted skeletal debris: both of these would fall into Folk's group of "micrites".

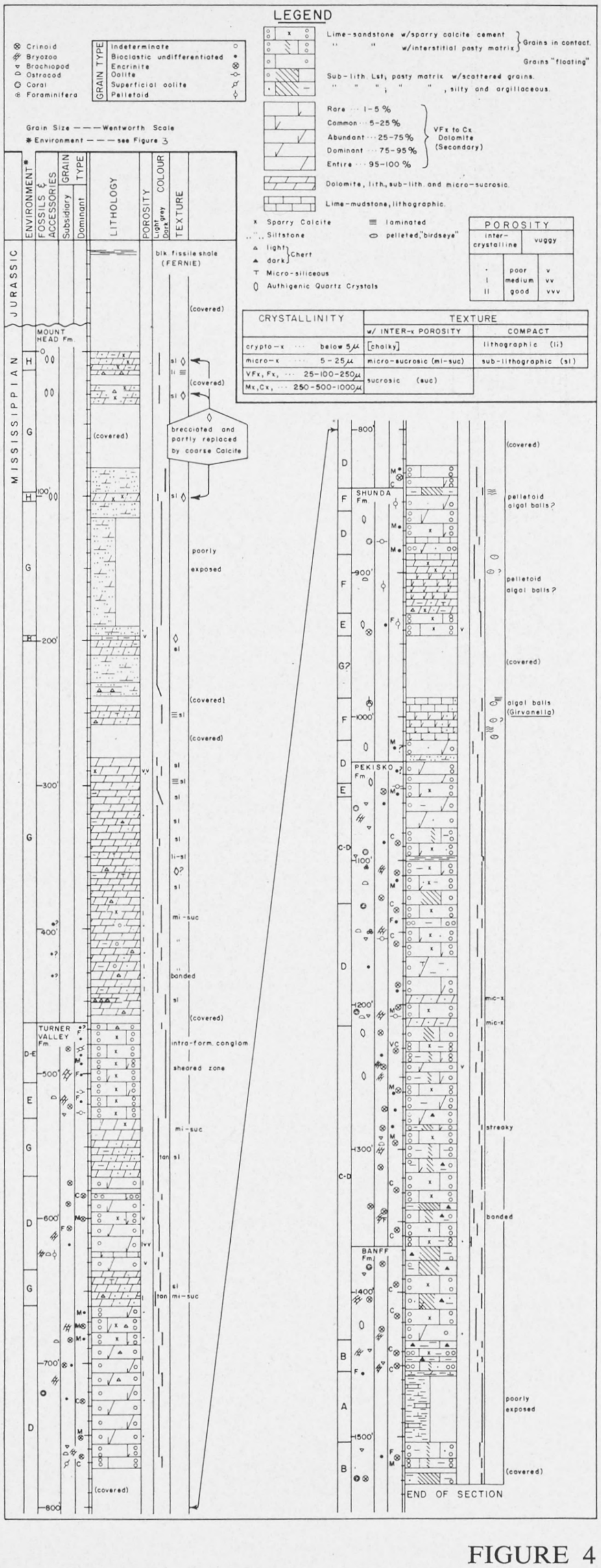


FIGURE 4

Summarized description of Mississippian outcrops along Canyon Creek on west flank of Moose Dome. This section was measured by G. V. Middleton for Shell Oil Co. at approximately the same locality as that described by Beach (1943, pp. 27, 28).

Black nodular chert is common in the dark, argillaceous, pasty Banff limestones, whereas it is absent in associated beds of bioclastic lime-sandstone. The clear relation bewteen distribution and conditions of original deposition, and the preservation of the silicified fossil detritus indicate an early rather than a late diagenetic origin for the chert, related to pH changes during initial burial. Working on cores of recent terrigenous muds from the deep basins off the Californian coast, Emery and Rittenberg (1952, p. 796) found that the pH increased to an alkaline value below the acidic top few inches of sediment. Amorphous silica is more soluble in alkaline water, and thus siliceous skeletal remains and volcanic glass that were entombed in this type of sediment would tend to be dissolved after burial. Silica gel is known to have an affinity for organic material, — witness the petrification of wood. During compaction, the connate, alkaline, silica-rich fluids would be squeezed out of these sediments and would tend to escape upwards. Where they passed through an abnormally rich organic layer in the acidic environment at the surface of deposition, the silica could no longer remain in solution and would be precipitated. Emery and Rittenberg suggest that this is the origin of many penecontemporaneous cherts.

PEKISKO FORMATION

Approaching wave base in phase B, lenses of somewhat lighter coloured bioclastic lime-sandstone (dominantly crinoid ossicles and bryozoan fragments) with interstitial pasty matrix (Pl.I.2) appear interbedded with the pasty, argillaceous cherty limestones. These sediments form the lower part of the Pekisko formation.

As the water became shallower and bottom conditions more turbulent in phases C and D, the lime-sands became dominant and the "dirty" sand with primary pasty matrix was replaced by clean-washed and often current-bedded bioclastic lime-sands (bryozoan encrinites) with a cement of clear secondary calcite (Pl.I.3). There is appreciable dolomitization in some of these upper Pekisko strata.

When the Pekisko seas became so shallow as to impede free inter-communication with the deeper ocean to the west, water temperatures rose, salinities started to increase and chemical deposition of calcium carbonate began. The oolites and spergenites of phase E at the top of the Pekisko are the first sign. Crinoid and bryozoan fragments are still important sediment contributors, and endothyrid foraminifera are common (Pl.I.4).

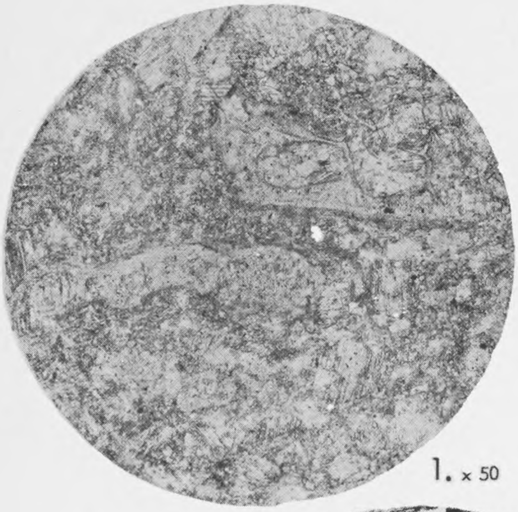
SHUNDA FORMATION

At this oolitic phase, the water depth was probably of the order of five fathoms or less. Some parts became so shallow that currents were diverted away or damped out and the seas were segmented into lagoons. The resulting hypersaline conditions in these areas of restricted circulation allowed the formation of lithographic lime-mudstones by chemical and biochemical precipitation (phase F). Still greater salinities led to the deposition of primary dolomites and anhydrites (phases G and H).

This first evaporitic maximum (phases F, G and H at Moose Dome) is represented by the Shunda formation, an interesting and controversial unit whose variations and correlations have been the subject of considerable recent debate (Moore, 1958, pp. 162-5).

The lower part of the Shunda is rarely well exposed at Moose Dome, being predominantly silty, cryptocrystalline (below 5 microns) to microcrystalline (5-25 microns) dolomite with shaly beds. The lithographic cryptocrystalline dolomites are believed to be primary, having been deposited as dolomite (or "protodolomite", — Graf and Goldsmith, 1956) mud. They commonly show lamination and slump structures (Pl.III.1). The lamination is often emphasized by selective recrystallization to a microcrystalline texture (Pl..III.2), controlled by the distribution of the argillaceous impurities.

Many of the microcrystalline dolomites were, however, deposited as fine bioclastic sediment and completely dolomitized during early diagenesis. Where such penecontemporaneous dolomitization was prevented by still earlier silicification (Pl.I.6) the secondary nature of the dolomite is obvious. Where the process has gone to completion, they cannot readily be distinguished from completely recrystallized primary dolomites. Krynine (1957) has emphasized this distinction between primary and early diagenetic (he uses the term "early syngenetic") dolomites, and qualitatively his conclusions fit closely with the discussion presented here. Quantitatively, he claims that ninety percent of the sedimentary dolomites of the whole geological column fall into one of these two groups.



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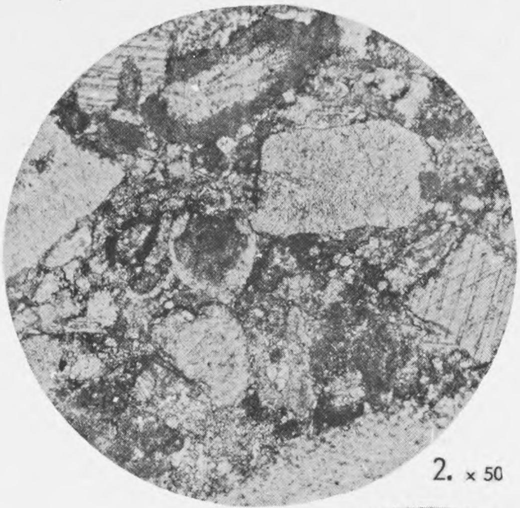

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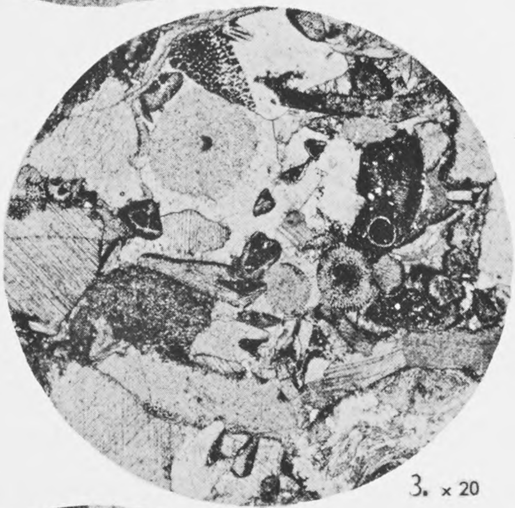

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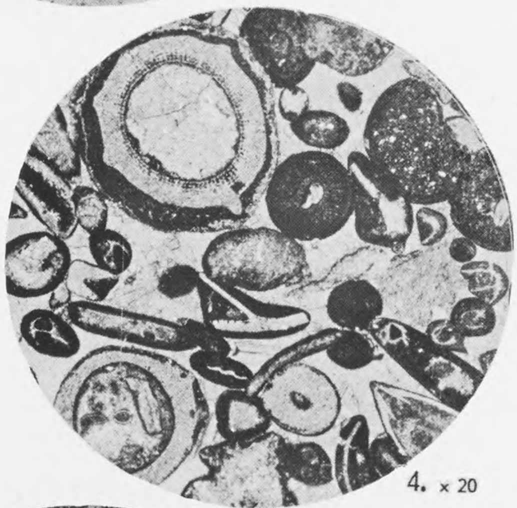

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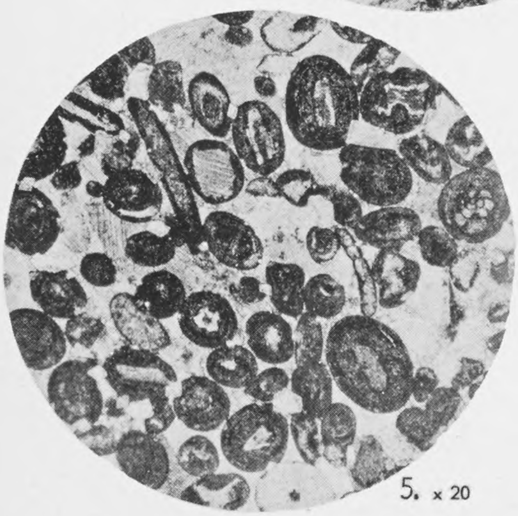

5. × 20

6. × 20

PLATE I

This estimate appears to the writer to be exaggerated, as subsequent dolomites formed during *later* diagenesis (epigenetic or "post-lithification" of some authors) are believed to amount to a great deal more than ten percent. Furthermore, confining attention to porous and permeable dolomites — the potential reservoir rocks for hydrocarbons — , it is believed that the large majority were dolomitized during late diagenesis: they are epigenetic rather than syngenetic. The process will be discussed further when dealing with the Turner Valley formation.

The silty Shunda dolomites are unfossiliferous. Some outcrops are brecciated and bedded anhydrite occurs in the subsurface, confirming the evaporitic association. These dolomites were probably formed in very shallow lagoons with high salinity and pH, similar to the recent occurrence described from South Australia by Alderman and Skinner (1957). The quartz silt commonly associated with these sediments suggests that they accumulated during a period of emergence when earlier deposited silts were exposed elsewhere and distributed by the wind. Similar silty dolomites of approximately the same age in southeast Saskatchewan are associated with anhydrite beds, and the zones of silt impurities can be traced as marker horizons into adjacent areas of normal marine carbonate deposition where evaporitic salinities were not attained (Porter, 1958).

PLATE I

1. Pasty limestone typical of the Banff and basal Pekisko formations; dark grey, compact, sublithographic, slightly argillaceous and silty. The limestone is composed of ill-sorted, rotted, skeletal material, whole and fragmentary, which merges into and contributes to the abundant pasty matrix. The two larger cellular structures are relics of fenestellid bryozoa.

Base of Pekisko formation; Canyon Creek section of Figure 4,, 1,337'-1,340'.

Analysis: 87-8-0-4 *

2. Encrinite with pasty matrix, dark grey, poorly sorted, slightly argillaceous. Rotting of some of the ossicles and other unidentifiable, blurred, skeletal grains has contributed to the interstitial pasty matrix which contains scattered dolomite rhombs. The presence of the matrix has limited welding by pressure solution and has prevented secondary growth in optical continuity on the ossicles.

Pekisko formation; Canyon Creek section of Figure 4, 1,077'-1,087'.

Analysis: 91-8-0-0.5 *

3. Encrinite, moderately sorted, coarse, non-porous. Pressure welding of the crinoid ossicles is dominant in the lower part, whereas the circular ossicle at upper left has been greatly enlarged by deposition of secondary calcite in optical continuity. The echinoderm plate above it retains part of its cellular structure. Other prominent grains include an echinoid spine (right centre), a part of a brachiopod shell (top left) and several bryozoan fragments. A few tiny authigenic quartz crystals are visible (lower centre).

Pekisko formation; Canyon Creek, Moose Dome.

4. Crinoidal bryozoan oolite (spergenite), coarse, well sorted; consisting of ossicles, ooliths, pelletoid grains, small fenestellid fragments (right), large ring-like echinoid sections, ostracods, and a conspicuous small brachiopod? shell (lower right). Several of the skeletal grains have superficial turbid layers, probably oolitic. Cemented by clear sparry calcite, some of which is in optical continuity with the echinoderm fragments (lower left). Non-dolomitic, non-porous.

Pekisko formation; Moose Dome Creek.

5. Oolite, well sorted; cemented by clear secondary calcite, with occasional scattered fine dolomite rhombs; non-porous. Most of the ooliths have skeletal nuclei, including crinoid ossicles and **Plectogyra** (right). The dolomite rhombs tend to occur at the points of grain contact and contain faint relics of the grain margins which they have replaced.

Top of Shunda formation; Elbow River, Moose Dome.

Analysis: 89-9-0-1 *

6. Cherty dolomite. Partial penecontemporaneous silicification has preserved relics of the original fine bioclastic sediment (mostly indeterminate spicular material with occasional recognizable fragments of bryozoa, ostracods and crinoid ossicles) and has cemented it with clear cryptocrystalline chert. The bioclastic origin has been obliterated in the turbid microcrystalline to very fine crystalline dolomite. Silicification preceded dolomitization.

Middle Dense member of Turner Valley formation; Moose Dome Creek.

* Versenate analysis in the following order:— Calcite, Dolomite, Anhydrite, Insolubles.

LIME-MUDSTONES

The conspicuous cliff-forming unit of the Shunda at Moose Dome consists of dark grey, cryptocrystalline, lithographic lime-mudstones. In Figure 4 it is shown near the middle and base of the formation. Elsewhere in the inlier, similar beds occur at the top of the Shunda and their thickness is markedly variable.

This lime-mudstone corresponds with part of the "Black Lime" of the Turner Valley oilfield, and is similar to the thin dark lithographic limestone that occurs at the top of the type section of the Shunda formation near Nordegg (Penner, 1958b). It shows many interesting lithological features and is believed to have originated either as an aragonite mud, which penecontemporaneously changed to calcite of similar crystallinity, or as a primary calcite mud. The latter view is favoured by the writer. In either case it formed by direct chemical or biochemical precipitation from the mildly supersaturated sea water, in shallow calm lagoons.

Pelleting: Almost all of these lime-mudstones are pelleted, presumably faecally by mud-scavenging organisms. The pellets may be closely packed or even squashed, or they may float in unpelleted lime-mud. Some of the lime-mudstones show a lamination caused by changes in the degree of pelleting and in the relative abundance and packing of ooliths, pisoliths and pelletoid grains.

Birdseyes: Besides being pelleted, almost all of the lime-mudstones contain small augen of clear sparry calcite, usually interconnected via films of calcite, producing a speckled, so-called "birdseye" texture (Pl.II.1 and 2). The eyes are sharply defined and have a variety of shapes. Some are simply infilled borings of bottom scavengers. The majority however are irregularly lenticular, varying in length from a fraction of a millimetre to several centimetres. They tend to be arranged with their long axes in the bedding, and squeezed between and around the pellets (Pl.II.3).

The birdseyes are believed to have formed soon after the sediment was deposited. A few inches below the soupy surface layers, slight gel conditions might be expected in these langoonal lime-muds. It is suggested that there was a tendency for the water to unmix from this medium, and to segregate as discrete water droplets. (This process is known to colloid chemists as "syneresis": it occurs, for instance in some silica gels). As the overburden increased some of the droplets would be squeezed out by feeding from one to the next. The interconnecting calcite films between the eyes are believed to be the escape paths of the water. Though the over-all movement would be upward, the droplets would tend to be aligned by the lamination of the sediment. The gel or plastic strength of the lime-mud was evidently sufficient to preserve most of the cavities till they were later filled with sparry calcite.

Another possible explanation is that the eyes were formed by shrinkage caused by desiccation during periods of slight emergence. This however is difficult to reconcile with their abundance: at least some of the lime-muds should have escaped elevation above sea-level during the critical early period of compaction.

A gas bubble origin related to the generation of hydrogen sulphide and methane in the anaerobic algal-rich sediment is a third possibility.

In the laminated lime-muds the eyes follow the banding (Pl.II.2) and sometimes emphasize a crude concentric structure suggesting spongiostromatous algae. Very similar structures with different growth forms (Anderson, 1950) have been described from analogous birdseye limestones of the Ordovician McLish formation of the Arbuckle Mountains by Ham (1954). His conclusion that the augen were caused by blue-green algae could equally well be applied to the Shunda limestones, although no trace of such algal filaments remains in the eyes. However, it seems more likely that the algal layers were important in creating planes of less cohesion along which the sediment parted due either to desiccation or gas generation, or which determined the shape, size, attitude and distribution of the segregating droplets of water as discussed above.

Other possible origins for the eyes that have been considered include the replacement of primary anhydrite and a grumelous (diagenetic) process. The shape and distribution of the eyes is not in accordance with the first, and their sharpness rules out the second.

Bahamite: A different interpretation of these sediments has been advanced by Beales (1958). He regards the individual pelletoid grains as "bahamiths,"[4] comparable with the authigenic aragonite sand grains that have been described as forming on the main part of the Bahama Banks (Illing, 1954). Beales developed this concept further, and what is here interpreted as a pelleted lime-mud (faecal pellets in a lime-mud matrix), Beales regards as "merged bahamite."

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4 In the following discussion the terms "oolith" and "bahamith" refer to the individual lime-sand grains of which the rocks "oolite" and "bahamite" are composed.

Though rocks of bahamite type do occur in the Mississippian of Alberta (Pl.II.6), the author believes that limestones similar to those illustrated in Plate II.3, 4, 5, and Figure 7 of Beales (1958), were more akin to the present day lime-muds west of Andros Island than to the lime-sands of the more open parts of the Bahama Banks.

Compaction: The sediment accumulated as a soupy lime-mud. It changed from liquid to plastic (or to a gel) while undergoing considerable bulk volume reduction during the initial period of rapid water loss. The birdseye cavities were formed while it was still soft and represent most of the compaction process. However, only the few that collapsed (see above) caused a reduction of bulk volume; the majority remained open and merely represent a compaction of the pelleted lime-mud within a framework that retained its approximate over-all dimensions. Cylindrical worm borings and occasional undeformed coiled nautiloids indicate that, apart from stylolitization, there was little further compaction beyond this plastic stage. During lithification the birdseyes were filled with calcite carried up by oversaturated connate water escaping from deeper horizons, where pressures (and hence the solubility of carbon dioxide and calcium carbonate) were greater, and where bulk volume reduction continued by stylolitization.

Algal balls, Stromatoliths, Pisoliths, and Ooliths: In addition to occassional faint relics of cyanophyceous algal threads (Pl.II.4) small stromatolith fragments emphasize the importance of algal activity. Indeed it is a moot point how far these lime-muds are biochemical precipitates and how far they are strictly physico-chemical. Large crenulate pisoliths floating in the matrix of pelleted birdeyed lime-mud (Pl.II.5) are believed to be algal. They grade into spherical non-crenulate ooliths, also floating in the matrix, and presumably also algal despite their similarity to individual ooliths of the associated clean, cross-bedded "orthodox" oolites described below. This appears to be an example of lithogenetic convergence.

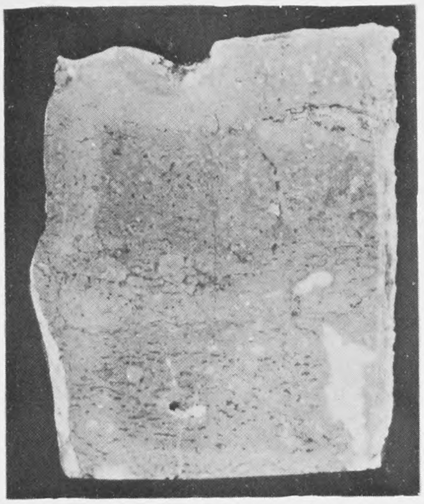
OOLITES

A thin bed of "orthodox" oolites occurs at the top of the Shunda at Moose Dome (Pl. I.5). The gains, which include much bioclastic material, were well sorted and packed and in some places there was pressure welding, forming mutual micro-stylolitic grain boundaries before the remaining pore space was filled with clear secondary calcite. Endothyrid foraminifera are common in this spergenitic rock. A few of the ooliths have pelletoid nuclei, but most are skeletal.

TURNER VALLEY FORMATION

The above cross-bedded oolites mark the return to more turbulent conditions, caused by a general inundation and a breaking down of the barriers that created the Shunda lagoons. We have passed the evaporitic peak of the cycle and come back to phases E and D of Figure 3. Normal salinities were soon restored and the crinoids returned to colonize the shallow banks and turn them into crinoid thickets. In this way were formed the thick sequence of encrinites of the Turner Valley formation. Crinoid ossicles were the dominant rock builder (Pl.III.3) but fenestellid bryozoa were abundant too (Pl.III.4); possibly they grew attached to the waving arms of the crinoid stems. Brachiopod fragments and ostracods are common and corals occur, occasionally in local communities suggesting very small patch reefs. Endothyrid foraminifera have been observed in thin-section, particularly near the top of the formation. Much of the limestone is cross-bedded, confirming the picture of shoals of loose drifting crinoid debris temporarily colonized and stabilized by a new crinoid meadow, only to be scoured away or recovered by the drifting debris from similar meadows nearby. The delicate fronds of *Fenestella* accumulated in the bottom-sets of the current-bedded encrinites and in local protected depressions which filled with finer debris, whereas rounded disarticulated bryozoan fragments accumulated with the ossicles in the fore-set beds.

The inter-relationships between porosity, dolomitization, and the many associated processes such as cementation and leaching constitute a very complex problem. In the present instance it is made even more complicated by the repetition of these processes during several subsequent periods of erosion. Relations between pairs of factors such as dolomite content and porosity are fairly clear, at least qualitatively (Towse, 1957), but the problem of distinquishing unequivocally between cause and effect in such an intricately interwoven network of processes has not been satisfactorily solved. Certain ideas are here put forward but more evidence from other areas will be needed to test them.



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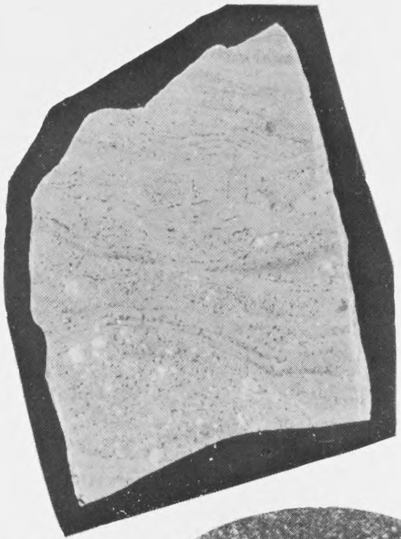

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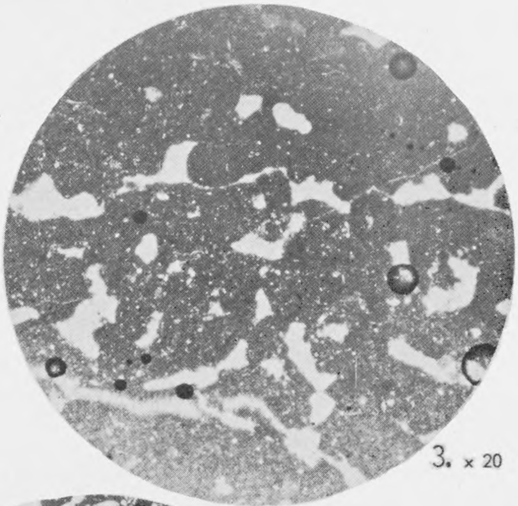

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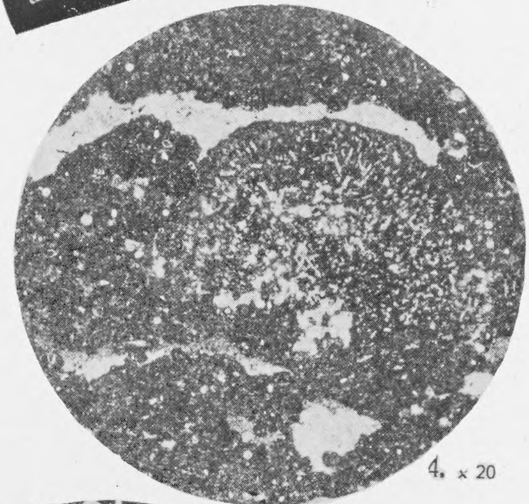

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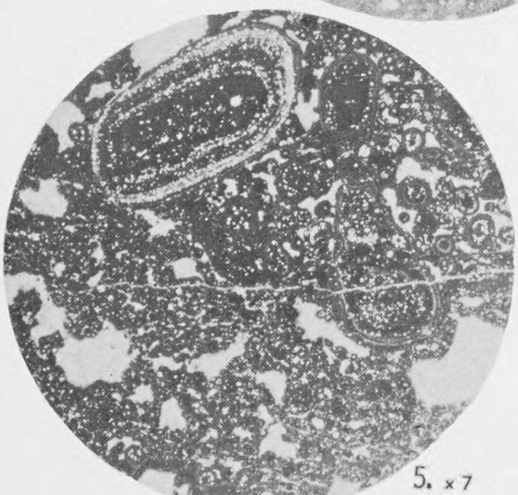

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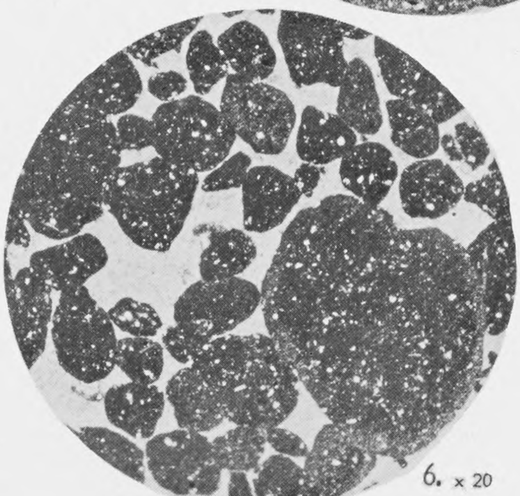

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PLATE II

PLATE II

BIRDSEYE LIME-MUDSTONES OF SHUNDA FORMATION AT MOOSE DOME

1. Dark grey, lithographic, pelleted; the larger pelletoid grains may be algal balls. The amoeboid to sinuously platy birdseyes are filled with clear calcite. Their shape depends on the plasticity of the lime-mud: in the upper half of the specimen the pellets were probably firmer and the birdseyes grade to normal inter-grain cement.

2. Dark grey, lithographic, irregularly laminated due to variations in pelleting; possibly part of a 'cabbage head' structure caused by spongiostromatous algae. Pellets are less abundant in the more uniformly lithographic bands where the birdseyes adopt a sinuous platy shape. In the pellet rich parts the birdseyes (dark and white) are irregularly amoeboid, fitting in between the pellets and grading into normal inter-grain cement. The white clots are caused by dolomite rhombs developed in the clear calcite of the birdseyes.

3. Sinuous amoeboid birdseyes, filled with clear sparry calcite, fit between and around elliptical lime-mud pellets (centre). Most of the latter are merged, suggesting that they were soft at the time of deposition and were probably faecal.

4. Faintly pelleted with microspheres, showing a Codiacean algal ball **(Ortonella?)** beneath a sinuous birdseye.

5. Pelleted with 'floating' ooliths. The laminae on the prominent small pisolith have been emphasized by selective dolomitization. Note the crenulate outlines of the larger ooliths (upper right) which are believed to be of algal origin.

TOP OF TURNER VALLEY FORMATION AT MOOSE DOME

6. Pseudo-oolite, well sorted and cemented by sparry calcite. The rounded pelletoid grains of cryptocrystalline calcite contain scattered quartz-silt particles and a few very fine dolomite rhombs. Several grains have been welded by pressure solution forming microstylolitic contacts, but they are not merged or squashed. They were therefore not plastic as in Nos. 1-5, and may have originated as 'bahamiths' rather than faecal pellets. The paler surface layer on the larger grain suggests superficial accretion, possibly algal.

Analysis:90-5-0-5 *

* Versenate analysis in the following order:— Calcite, Dolomite, Anhydrite, Insolubles.

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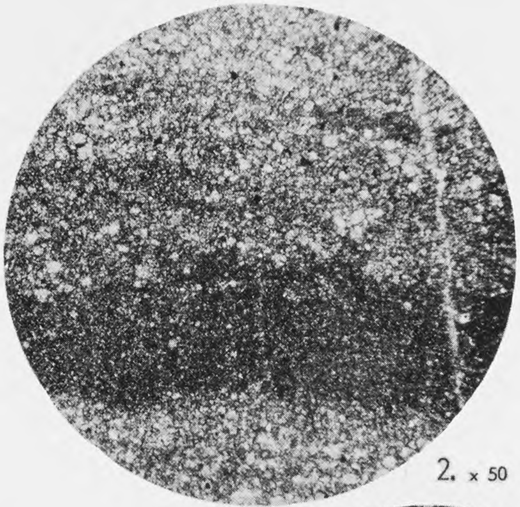

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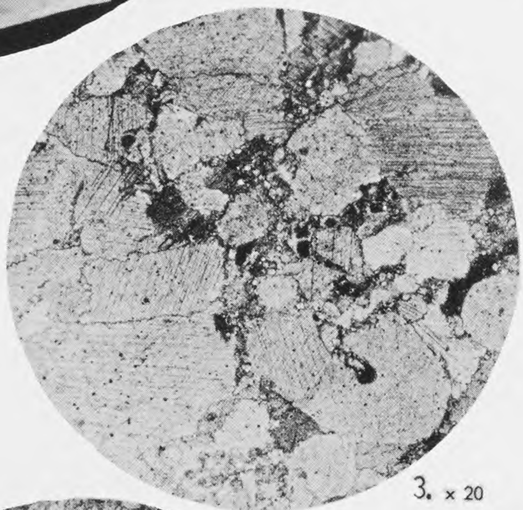

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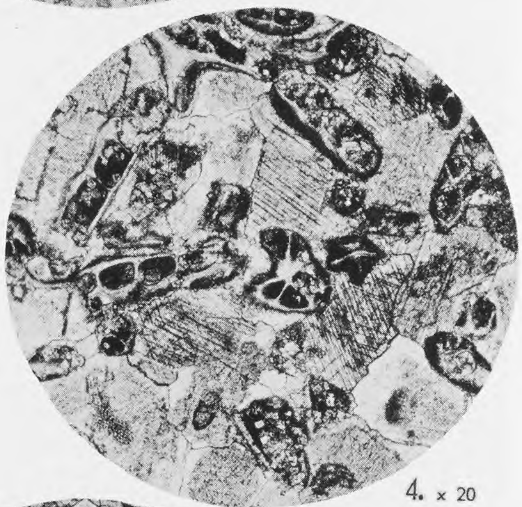

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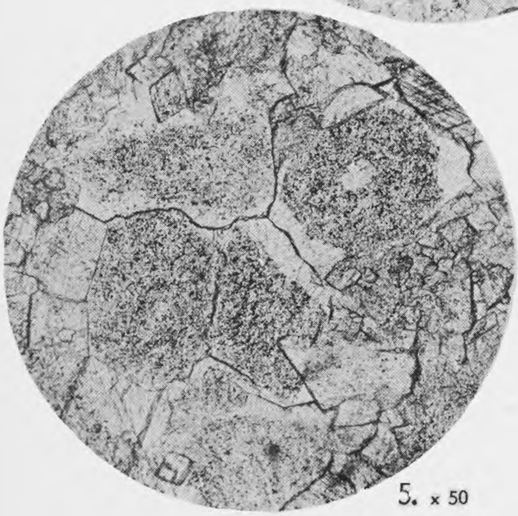

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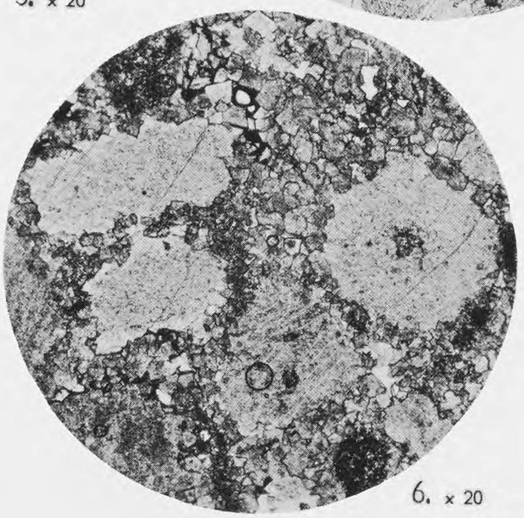

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PLATE III

PLATE III

SHUNDA FORMATION; ELBOW RIVER, MOOSE DOME

1. Primary dolomite-mudstone, tan-grey to dark grey, lithographic, finely laminated, with small scale compaction structures and mottling; slightly argillaceous, particularly in the darker bands which are also slightly siliceous.

Analysis: 9-85-0-6 *

2. Section from the central part of No. 1. The changes in crystallinity which cause the lamination are due to partial selective recrystallization from cryptocrystalline (turbid) to microcrystalline. Argillaceous impurities are concentrated in the turbid bands.

TURNER VALLEY FORMATION, AT MOOSE DOME CREEK

3. Encrinite showing good pressure solution welding of the ossicles. A few small fenestellid bryozoan cells are visible at right centre.

Analysis: 86-12-0-0.5 *

4. Encrinite, light grey, well sorted, containing abundant fenestellid bryozoan fragments. There has been considerable enlargement of the crinoid ossicles (turbid) by deposition of clear calcite in optical continuity, and pressure welding also occurs: neither of these processes has affected the bryozoan grains. Vestiges of the original pore structure can be seen in the ossicle at lower left. Rare dolomite rhombs occur along grain borders and within bryozoan fragments. There is poor inter-crystalline porosity.

Analysis: 82-15-0-3 *

5. Encrinite, light grey, well sorted, with poor inter-crystalline porosity. The turbid ossicles have been enlarged by deposition of clear calcite in optical continuity. The lower pair of ossicles have been welded by pressure solution. The dolomite rhombs follow the enlarged grain contacts (upper left) and were therefore formed after the growths of clear calcite.

Analysis: 68-33-0-0.5 *

6. Encrinite, coarse, well sorted; completely dolomitized with inter-crystalline and vuggy porosity (upper centre, partly filled with dark bakelite).

The fine sucrosic matrix of dolomite subhedra and the ossicles pseudomorphed by single dolomite crystals appear to represent two distinct generations of dolomite. Relics of clear borders within the indented margins of some of the ossicles suggest there was cementation by calcite in optical continuity before the dolomitization of the matrix. A period of calcite leaching may have intervened to create the porosity after the dolomitization of the matrix and before the pseudomorphing of the remaining calcite ossicles by dolomite.

Analysis: 0.1-100-0-tr *

* **Versenate analysis in the following order:— Calcite, Dolomite, Anhydrite, Insolubles.**

It is clear that the original sediment of the Turner Valley formation, whether later dolomitized or not, was a bioclastic lime-sand. The bulk of the sediment was composed of crinoid ossicles, and the rock is therefore an encrinite. Studies of modern crinoids show that these organisms contain between 6 and 14 per cent of magnesium carbonate in solid solution in their calcite skeletons (Clarke and Wheeler, 1922; Chave, 1954 p. 278). Assuming comparable initial compositions for Mississippian and modern crinoids, it follows that in the many encrinites with a very small magnesium content — of the order of one or two per cent — magnesia must have been lost from the original ossicles, as postulated by Chave; and this may account for an appreciable proportion of the dolomite found in other parts of the formation (Van Tuyl, 1916).

However, there is too much dolomite present for it all to have been formed in this way: the bulk of the magnesia must have been introduced from outside during some stage of diagenesis. It is the writer's belief that most of the magnesia was brought by escaping connate waters, squeezed out of older buried sediments that were compacting at deeper levels. These compaction fluids escaped by the easiest route available, namely through the most permeable formations. The more permeable the carbonate sediment, the more likely it was to be subsequently dolomitized. The rocks are dolomitic because they were permeable, rather than being permeable because they are dolomitic.

During burial there was compaction of this lime-sandstone, principally by pressure solution at the points of contact of the grains. Bryozoan fragments and other non-unicrystalline skeletons were less affected than the crinoid ossicles and blastoid spines and plates, which were pressed into each other developing mutual sutured contacts (Pl. III.$_3$). No doubt much of the calcite was removed in solution to be deposited elsewhere, but some was immediately redeposited on unstressed surfaces of the ossicles in optical continuity (Pl.III.$_4$, $_5$). In this way the over-all porosity and permeability of the encrinites was severely reduced. Some beds, in many cases the best sorted and purest encrinites, have been made completely impermeable. Others, including lime-sands which were not so well sorted and consisted of a mixture of crinoid, bryozoan, brachiopod and coral fragments set in a finer matrix of more comminuted debris, were less affected.

The dolomitization of these encrinites started along the contacts between ossicles that had already been enlarged by crystal growth (Pl.III.$_5$). The dolomitization was therefore later than the calcite cementation. As outlined above, the latter is believed to have occurred under a considerable sedimentary load, sufficient to produce pressure solution between adjacent grains. This leads to the conclusion that this type of dolomitization occurred during late diagenesis (epigenetic), contrary to the common view that it was a penecontemporaneous phenomenon (e.g. Krynine and Folk, 1950, p. 6; Douglas, 1953, p. 74).

In the initial stages, dolomitization attacked the interstitial finer bioclastic debris and did not affect the largest skeletal fragments, particularly the ossicles. In the poorly sorted lime-sandstones, we are therefore left with ossicles floating in a patchy dolomitic matrix, whereas the purer, better sorted encrinites merely show threads and films of dolomite rhombs growing along the ossicle contacts. The conversion to dolomite of the larger ossicles seems to have been a second phase, and there is evidence to suggest that it was separated from the first phase by a period of calcite leaching. The margins of the ossicles were invaded by fine rhombs during the first phase; when the remaining ossicles were dolomitized in the second stage, instead of being replaced by interlocking subhedral rhombs they were pseudomorphed by single dolomite crystals. Occasionally, the crinoid outlines, as in Plate III.$_6$, or even remnants of their cellular structure are preserved, so the process must have gone on in the solid; it was not a vug filling. Those ossicles that were leached out after the first phase of dolomitization remain as empty vugs or are merely lined with a new growth of euhedral rhombs.

The determination of the time relationships of such diagenetic and metasomatic phenomena is notoriously difficult, and in most cases the microscopic evidence is capable of more than one interpretation. Whether the above picture of two or more separate phases of pre-Recent dolomitization is correct (there has also been some Recent dolomitization along hair-line cracks related to the present erosion surface), or whether they overlapped is not known. On either interpretation it seems evident that leaching of calcite has been important. The dolomitized bioclastic sands of the Turner Valley formation are certainly more porous and permeable than those that have not been dolomitized. The fundamental control by the nature of the original sediment, and the effect of varying degrees of subsequent compaction and cementation have already been discussed. Calcite leaching may be later, or it may be part and parcel of this process, extending and modifying the porosity and permeability of the limestone, and hence affecting the ease of access for dolomitizing fluids according to the stage in the diagenetic-metasomatic sequence at which it occurred.

MOUNT HEAD FORMATION

The youngest Mississippian strata preserved at Moose Dome form a dominantly evaporitic unit, about five hundred and fifty feet thick. It is covered unconformably by black shales of the Fernie group (Jurassic) with a thin basal chert pebble conglomerate.

Douglas (1953) has correlated this sequence with all but the topmost member of his Mount Head formation in the Livingstone Range of the Rocky Mountains, thirty miles to the south. To the west in the Misty Range the correlative strata are more complete and in a more dominantly marine facies, similar lithologically and faunally to the Meramecian limestones of Illinois (Raasch, 1958).

The sequence at Moose Dome probably formed along the lagoonal eastern shores of the Mount Head seas. Mud cracks and raindrop prints have been observed in some of the silt beds, which may be deltaic. There appear to be two evaporitic phases (believed by Douglas to correspond to his Salter and Marston members) represented by silty dolomites and solution breccias; anhydrite beds occur in the subsurface at these horizons. They are separated by periods of normal salinity when thin bioclastic and pseudo-oolitic limestones were formed, giving the Mount Head sequence a cyclic pattern (not shown in Figure 3b).

Exposures of the Mount Head formation at Moose Dome are poor, and detailed discussion of this unit is therefore omitted. Lithologically, the sediments can be matched closely in the evaporitic sequence of the Shunda formation described above. The dominant rock type is a cherty microcrystalline dolomite in which dolomitization was probably penecontemporaneous but was preceded by still earlier chertification (cf. Pl.I.6). Silty cryptocrystalline primary dolomites are also present. The breccias are of interest and include a variety of types. Some are believed to be penecontemporaneous and others are interpreted as pseudobreccias caused by selective recrystallization. Both of these were early diagenetic phenomena and both have been involved in later brecciation attributed to solution of associated anhydrite beds. A fuller discussion of the origin and significance of these breccias is reserved for publication elsewhere.

CONCLUSION

This analysis of Mississippian sedimentation and the factors that controlled it has dealt with a very limited area, and emphasis has been placed on the changing environment of deposition. The same story could be outlined in other parts of the Western Plains of Canada. For example, the Mississippian of southeast Saskatchewan, in which considerably more than half a billion barrels of oil reserves have been discovered in the last four years, illustrates a very similar sedimentary history (Fuller 1956; Porter 1958; Edie 1958) in which the sequence of phases of Figure 3a can be recognized. After a rapid transgression, there, as in Alberta, the Mississippian can be regarded as a period of major regression, on which cyclic sea level changes imparted their characteristic stamp.

Thus, in Mississippian time the area now occupied by the Western Canadian Plains was part of a broad epicontinental shelf, deepening westwards and southwestwards below wave base away from the partly emergent Canadian Shield. The sediments on the Shield margin suggest a dry hot climate, and the profusion and the variety of fossil debris in the shelf carbonates testify to warm shallow seas. This is further confirmed by the evidence of chemically precipitated limestones where restricted lagoonal conditions allowed the water to become supersaturated with calcium carbonate. The environmental belts of argillaceous pasty limestones, bioclastic lime-sands, oolites, lagoonal lime-muds and evaporites moved back and forth with changes in sea level, producing the corresponding vertical cyclic sequence that is now exposed in Moose Dome.

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STRUCTURAL GEOLOGY OF THE MOOSE MOUNTAIN AREA, ALBERTA

C. D. A. DAHLSTROM and G. G. L. HENDERSON [1]

Abstract

The surface geology of the Moose Mountain area provides excellent illustrations of type structures and fundamental processes in foothills geology. The area consists of a series of fault plates separated by major sole thrusts.

In one instance the upper and lower boundary sole thrusts converge to form a wedge-shaped fault plate, a typical foothills structure. Study of the junction relationships indicates the lower or more easterly sole thrust was formed, and probably folded, before the upper or more westerly sole thrust developed.

All thrusts eventually terminate laterally or vertically. Lateral die-out is illustrated in several cases where it is apparently accomplished by transfer of motion to adjacent faults. Evidence of vertical die-out is provided by the Turner Valley sole fault where motion is dissipated upward in a crumpled zone along the eastern edge of the Foothills.

Introduction

The structure of the Foothills and Front Ranges of the Rocky Mountains between latitudes 50° 30′N and 51° 15′N is described in this paper. Regional geology is shown in Figure 1 (back-pocket), which was compiled from maps and reports of the Geological Survey of Canada by G. S. Hume (1931, 1940, 1941, 1942), C. O. Hage (1946), H. H. Beach (1941, 1943), and from other published maps by J. A. Allen and J. L. Carr (1947), M. B. B. Crockford (1949), L. M. Clark (1949) and G. G. L. Henderson and R. J. W. Douglas (1954).

Stratigraphy

The stratigraphy of this part of the Disturbed belt has been adequately described by Beach (1943) and Clark (1949). The reader is referred to the tabular summary which accompanies the Road Log of Field Trip No. 2.

Structural Geology

Several major fault plates are recognized in the southern part of the area. Each is bounded above and below by major sole thrusts and is named from the underlying sole thrust or from some prominent topographic feature. The main plates are, from west to east, McConnell, Dyson Mountain, Mount Barwell, Highwood, and Turner Valley. The latter overlies the undisturbed Plains strata. The sole thrusts, from west to east, are the McConnell, Dyson Mountain, Barwell Mountain, Outwest and Turner Valley. The McConnell is the most extensive of the sole thrusts and can be traced northward for at least two hundred miles. The Dyson Mountain and Barwell Mountain thrusts terminate within the map area. The northern limits of the Turner Valley and Highwood plates are uncertain because the boundary faults cannot be followed with certainty in the vicinity of the Bow River.

Each plate is treated individually in the following discussion. The significant structures in each are described and the conclusions which may be drawn are presented as they arise. The sole thrusts are major structural features and a separate section is devoted to each following the discussion of the overlying plate.

McCONNELL PLATE

The McConnell plate includes several major structures: the Lewis, Mt. Rundle, Lac des Arcs, Exshaw and Fullerton faults and the Nihahi, Fairholme and Misty Range folds.

The Lewis thrust is a major sole fault in the southern Disturbed belt, but within the map area it is a relatively minor feature which dies out in a crumpled zone in the hanging wall of the Mt. Rundle thrust.

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The Mt. Rundle thrust is a substantial thrust which dies out southward in the core of the Misty Range structure. It is probably significant that the die-out ends of the Mt. Rundle and Lewis thrusts overlap and that, in the overlap area, tears, bounded above by the Lewis thrust and below by the Mt. Rundle thrust, are common. It is believed this arrangement represents motion transfer from one thrust fault to the other thrust fault through a series of tear faults.

The Lac des Arcs fault occurs on the fore-limb of the Misty Range anticline. To the southwest it dies out on the plunging end of the Misty Range in the same general area where the Coleman fault begins. This overlap strongly suggests another motion transfer system. Northward the Lac des Arcs fault continues beyond the map boundaries.

BLOCK DIAGRAM OF FULLERTON TEAR

THE EXSHAW FORMATION IS THE HORIZON SHOWN

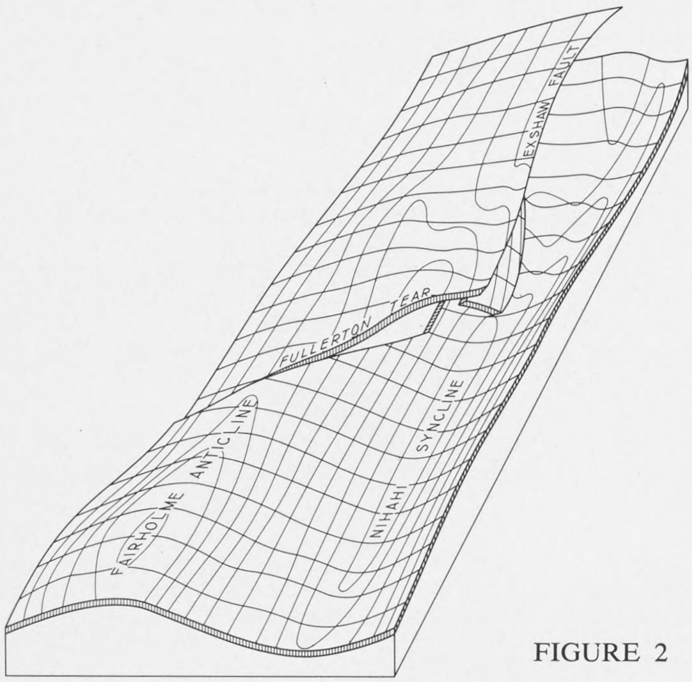


FIGURE 2

The Exshaw fault originates as a branch of the Lac des Arcs fault near the Ghost River and it continues south to terminate against the Fullerton tear fault. South of the Fullerton tear the structure between the Lac des Arcs and McConnell faults is a simple anticline-syncline pair (Fairholme anticline and Nihahi syncline). The amount of shortening to the north and south of the Fullerton tear appears to be consistent, although in the one case it is accomplished primarily by faulting and in the other by folding. (See Fig. 2). The Fullerton tear was the essential mechanism which permitted these two methods of shortening to operate side by side and, of course, simultaneously.

Three areas of motion transfer, i.e. Lewis-Mt. Rundle pair, Lac des Arcs-Coleman pair and the Exshaw-Fairholme-Nihahi system, have been mentioned above. It is difficult for such a motion transfer system to operate unless the elements within it are all connected to a common plane of motion. In all of these instances the common plane of motion is believed to be the McConnell thrust which, as shown in the cross-section by North and Henderson (1954), probably extends as a relatively flat fault at least as far west as the Bourgeau thrust. The conclusions presented in Henderson's and North's cross-section were derived from field evidence obtained in the Bow River area, whereas the conclusions presented here are derived from regional patterns. The two are in accord. The implication of the foregoing conclusion is that all of the thrust faults at these latitudes, east of the Bourgeau fault and west of the McConnell thrust, are imbricates of the McConnell.

MCCONNELL FAULT

The McConnell fault extends from Livingstone Falls northward at least to the Brazeau River, a distance of 200 miles. As indicated in the preceding section, it is a relatively flat dipping thrust. At several localities the fault is demonstrably folded. In the vicinity of Mt. Head, to the south of the map area, Douglas (1959) has described and documented a fold in the McConnell fault which is asymmetric with a vertical east limb. Within the map area Clark (1949) has demonstrated a monoclinal flexure, from west-dipping to flat-lying, at Mount Yamnuska in the vicinity of the Bow River. Presumably, this flexure represents the west flank and crest of an anticline in the McConnell fault at a location where the east limb has been eroded. To the north of the map area at Panther River, the McConnell fault is folded over the Panther River anticline.

The regional pattern of salients and re-entrants along the surface trace of the McConnell thrust shows clearly its folded character. (See A.S.P.G. Map No. 1, Southern Rocky Mountains of Canada Tectonic Compilation Map). The Panther River high is in a marked re-entrant, whereas the Black Rock klippe is on the east tip of a salient occupying the plunge depression between the Panther River and the Moose Mountain structures.

DYSON MOUNTAIN PLATE

The principal structures in the Dyson Mountain plate are the Sullivan Creek anticline, the Mt. Ware anticline, the Forgetmenot anticline and the Dyson Mountain syncline.

The Sullivan Creek anticline is a major fold extending considerably to the south of the mapped area. Surface data indicates that at least two relatively thin thrust sheets of Blairmore, Kootenay and Fernie rocks are involved in the anticline.

The Mt. Ware anticline is a doubly plunging compound anticline which is in en echelon arrangement with the Sullivan Creek and Forgetmenot structures.

The north end of the Forgetmenot anticline is a drag fold on the back-limb of the Moose Mountain structure. To the south the amplitude of the fold increases and the Dyson Mountain fault develops on the fore-limb. At its southern end the fold plunges under the west flank of the Dyson Mountain syncline.

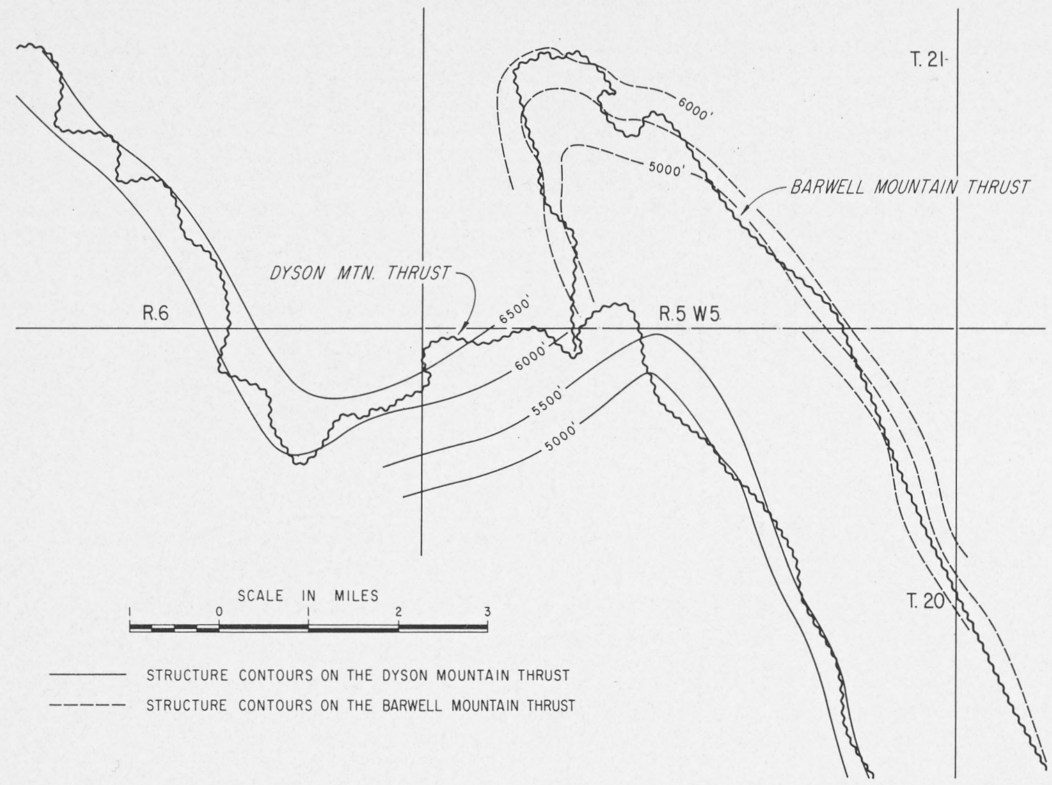
The above three anticlines are in en echelon arrangement on the west limb of the Dyson Mountain syncline. Although distinctly separate structures at Mississippian to Blairmore levels, they are not reflected in the disposition of the Cardium outcrop either on the west or the east. (Fig. 1). Therefore, in this area at least, there is a structural disharmony between the lower Blairmore and Cardium levels which, presumably, is taken up by flowage or minor faulting in the upper Blairmore and Blackstone.

The Dyson Mountain syncline is a broad open feature at the north end, but to the south it tightens and is complicated by faulting.

DYSON MOUNTAIN FAULT

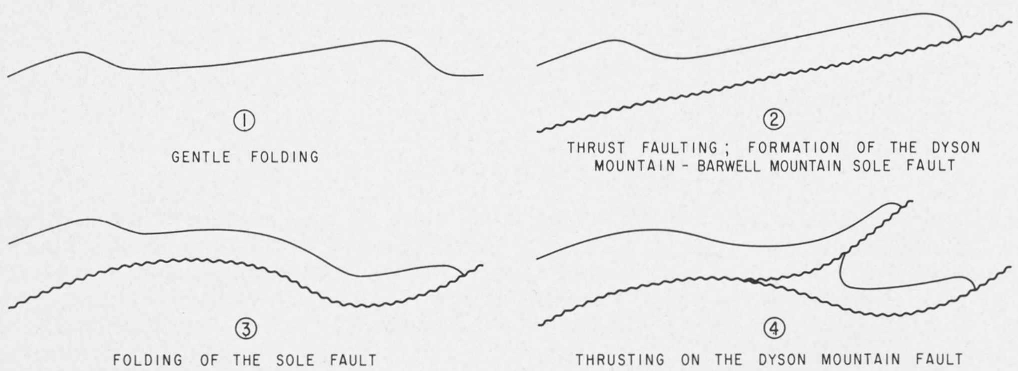
The Dyson Mountain fault originates as a minor fault on the fore-limb of the Forgetmenot anticline near the north end of Moose Mountain. Displacement increases rapidly southward and, in the southern part of the map area, it is of the order of six to seven miles. This increase in displacement takes place over a distance of twenty miles and represents an angular rotation of 20 degrees in the hanging wall of the fault. It is interesting to note that there is a bend in the axis of the Forgetmenot anticline on the Elbow River of some 20 degrees and that there is a similar bend in the Sullivan Creek structure near the north boundary of Township 18. The Mt. Ware anticline is oblique to the regional trend and parallel to the bent portion of the Forgetmenot anticline and Sullivan Creek structures. These changes in structural trends may be due to the abrupt increase in motion on the Dyson Mountain fault.

As described by Hage (1942), the Dyson Mountain thrust is folded in a terrace with the dips changing from west to flat to west. (See Fig. 3). In the section to follow, the discussion will be extended to include the Barwell Mountain fault which is intimately related to the Dyson Mountain thrust.



STRUCTURAL CONTOUR PLAN OF THE DYSON MOUNTAIN AND BARWELL MOUNTAIN THRUST PLANES (PARTLY AFTER HAGE, 1942 p.76)

FIGURE 3



DIAGRAMMATIC SKETCH SHOWING THE STAGES OF DEVELOPMENT OF THE DYSON MOUNTAIN AND BARWELL MOUNTAIN THRUST PLATES

FIGURE 4

MOUNT BARWELL PLATE

The Mount Barwell plate has been mapped as a wedge shaped fault plate between the Dyson Mountain and Barwell Mountain thrusts. This is the general shape which all fault plates must eventually assume but it is rare that plunge permits the typical wedge shape to be observed. The structure within the plate is a simple south plunging anticline-syncline pair which has been partially overriden by the younger Dyson Mountain thrust.

BARWELL MOUNTAIN FAULT

The Barwell Mountain fault is a gently dipping, synclinally folded thrust which terminates against the Dyson Mountain fault. (Fig. 3). As Hage (1942) has pointed out, it is apparent that the Barwell Mountain thrust was the front part of the Dyson Mountain sole thrust during the early stages of faulting and that the eastern steep-dipping part of the Dyson Mountain fault developed later as an imbrication from the sole thrust. (Fig. 1, cross-section No. 12). Hage felt that both the Barwell Mountain and Dyson Mountain faults were formed before the sole fault was folded. The writers prefer a somewhat modified sequence of overlapping structural events. (See Fig. 4):

1 Open folding.

2 Development of the Barwell Mountain - Dyson Mountain sole thrust and major motion thereon.

3 Folding which produced the Moose Mountain anticline and Mount Quirk syncline and folded the sole thrust.

4 Development of the steeper dipping eastern part of the Dyson Mountain thrust as an imbrication of the original sole thrust.

5 Motion on this imbricate thrust producing the east flank of the Dyson Mountain syncline and overriding of the Mount Barwell plate.

The only significant difference between the two interpretations is the relative age of the folding of the sole thrust and the development of the Dyson Mountain imbrication. The writers believe that the sole fault was folded prior to the development of the imbrication. Two lines of evidence exist which are strongly suggestive but not conclusive.

1. The steep-dipping part of the Dyson Mountain fault (the Dyson Mountain imbrication) dips at 45 to 55 degrees to the west. The east dipping part of the Barwell Mountain fault dips at 25 to 30 degrees. Before folding it probably had a gentle west dip. To restore the Barwell Mountain fault to its original position prior to folding would require a rotation of 30 to 35 degrees. (Fig. 1, cross-section No. 12). If the Dyson Mountain imbrication existed prior to the folding then it too must be rotated by 30 to 35 degrees to restore it to its original position, and the original dip would have been 75 to 90 degrees to the west. This is not impossibly steep but the writers feel that it is highly improbable.

2. The occurrence of minor late imbrications at inflection points or anticlinal crests in a folded fault is a typical disturbed belt feature. A well known example is that at Mount Yamnuska as illustrated by Clark (1949). C. Warren Hunt's map of the Panther River area (1956) also shows an example which might well be the continuation of the minor fault at Yamnuska. In most instances these younger imbrications have relatively minor displacement. The Dyson Mountain fault is unusual in having considerable motion.

An interesting feature of the regional structural pattern is the alignment of the Moose Mountain anticlinal and Dyson Mountain synclinal axes. The two structures are separated by the Dyson Mountain and Barwell Mountain thrusts, which are folded in harmony with the underlying structure. On the east side, the change from the east dipping flank of the Moose Mountain anticline to the west dipping flank of the Dyson Mountain syncline is accomplished by the introduction of the wedge shaped Mount Barwell plate which fills the Mount Quirk syncline. (Fig. 1, cross-section Nos. 8 to 13). The west flank of the Moose Mountain anticline changes to the east-dipping flank of the Dyson Mountain syncline through the development of the en echelon Forgetmenot, Mount Ware and Sullivan Creek anticlinal system. (Fig. 1).

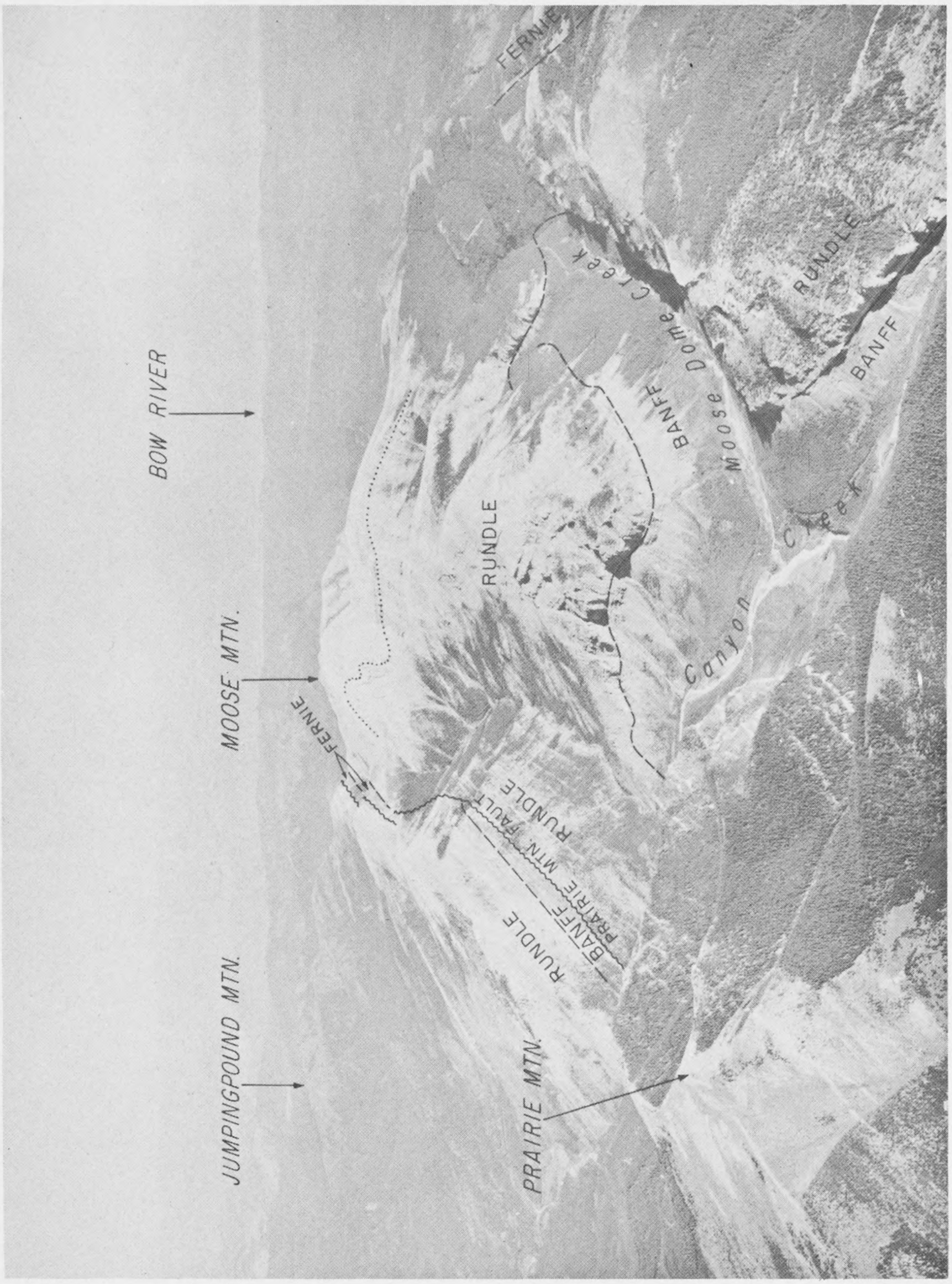


PHOTO BY K. T. HYDE

MOOSE MOUNTAIN

PLATE I

There is often considerable discussion in foothills literature as to whether the folding begins before faulting or whether folding is a consequence of faulting. The reader will notice in the foregoing discussion that both ideas have been used. The writers (Henderson and Dahlstrom, 1959), believe that the existence of fault cut-offs at right angles to the bedding requires that folding precede faulting. This phenomenon is exhibited on the fore-limb of the Forgetmenot anticline and on the hanging wall of the Prairie Mountain anticline (Fig. 1 cross-sections) and is common in the Foothills. These structures are considered to be examples of folding prior to faulting. On the other hand the east limb of the Dyson Mountain syncline is a clear case of the alternate hypothesis in which folding is a consequence of faulting. Here, as previously explained, fault motion has produced a syncline which directly overlies an anticline produced by normal folding processes.

HIGHWOOD PLATE

The Highwood uplift and the Moose Mountain anticline are the two main features of the Highwood plate. These two structures are en echelon and may be separated by a fault.

The Highwood uplift at the Highwood and Sheep Rivers is expressed at the surface by a complex of folded and faulted Blairmore and Colorado beds. Drilling has disclosed that this grossly anticlinal area is underlain by Mississippian limestone above the Outwest fault. Further north two similar but smaller uplifts occur, one at Fisher Mountain and the other at Bragg Creek. Both uplifts have been drilled but no limestone was found above the Outwest fault.

The Moose Mountain structure consists of two parts: on the east, a large compound, slightly asymmetric, doubly plunging anticline — the Moose Mountain anticline (Fig. 5, Pl.I.) and, on the west, a back-limb thrust sheet, — the Prairie Mountain thrust sheet. The Moose Mountain anticline culminates at Moose Dome Creek. South of the culmination the amplitude of the fold decreases, as a subsidiary anticline appears on the west flank (Fig. 1, cross-section No. 8). This subsidiary fold grows at the expense of the Moose Mountain anticline until, south of the Elbow River, it becomes the dominant structure (Fig. 1, cross-section Nos. 10 and 11). North of the culmination the Moose Mountain anticline plunges beneath the Prairie Mountain thrust sheet (Fig. 1, cross-section No. 3).

The Prairie Mountain fault originates south of the Elbow River as a back-limb thrust. Northward the displacement increases markedly and an anticlinal fold appears in the hanging wall. It is interesting to note that the increase in displacement on the Prairie Mountain fault coincides with a decrease in displacement on the Dyson Mountain fault. On the north plunging end of the Moose Mountain anticline the Prairie Mountain fault is folded just as the Dyson Mountain thrust is folded over the south plunging end.

The Mount Quirk syncline is present in Upper Cretaceous surface rocks southeast of Moose Mountain, directly underlying the synclinal fold in the Barwell Mountain thrust. At the north end of Moose Mountain, in the vicinity of the Bow River, there seems to be a structure comparable to the Mount Quirk syncline but it is complicated by faulting and exists only as a structural terrace at Belly River level.

OUTWEST FAULT

The Outwest fault is the sole fault underlying the Highwood uplift. The fault is known from well data to have a large throw and is probably, but not certainly, folded. At the surface the fault can be traced to the north of the Elbow River where it is lost in a plexus of minor faults.

TURNER VALLEY PLATE

This plate has been described in several papers [Gallup (1951), Link and Moore (1934) and Hume (1938 and 1939)], so that no description will be presented here.

TURNER VALLEY FAULT

Drilling within and near to the Turner Valley field has established that the Turner Valley fault is a major sole thrust. This is somewhat anomalous since the fault at surface is singularly unimpressive.

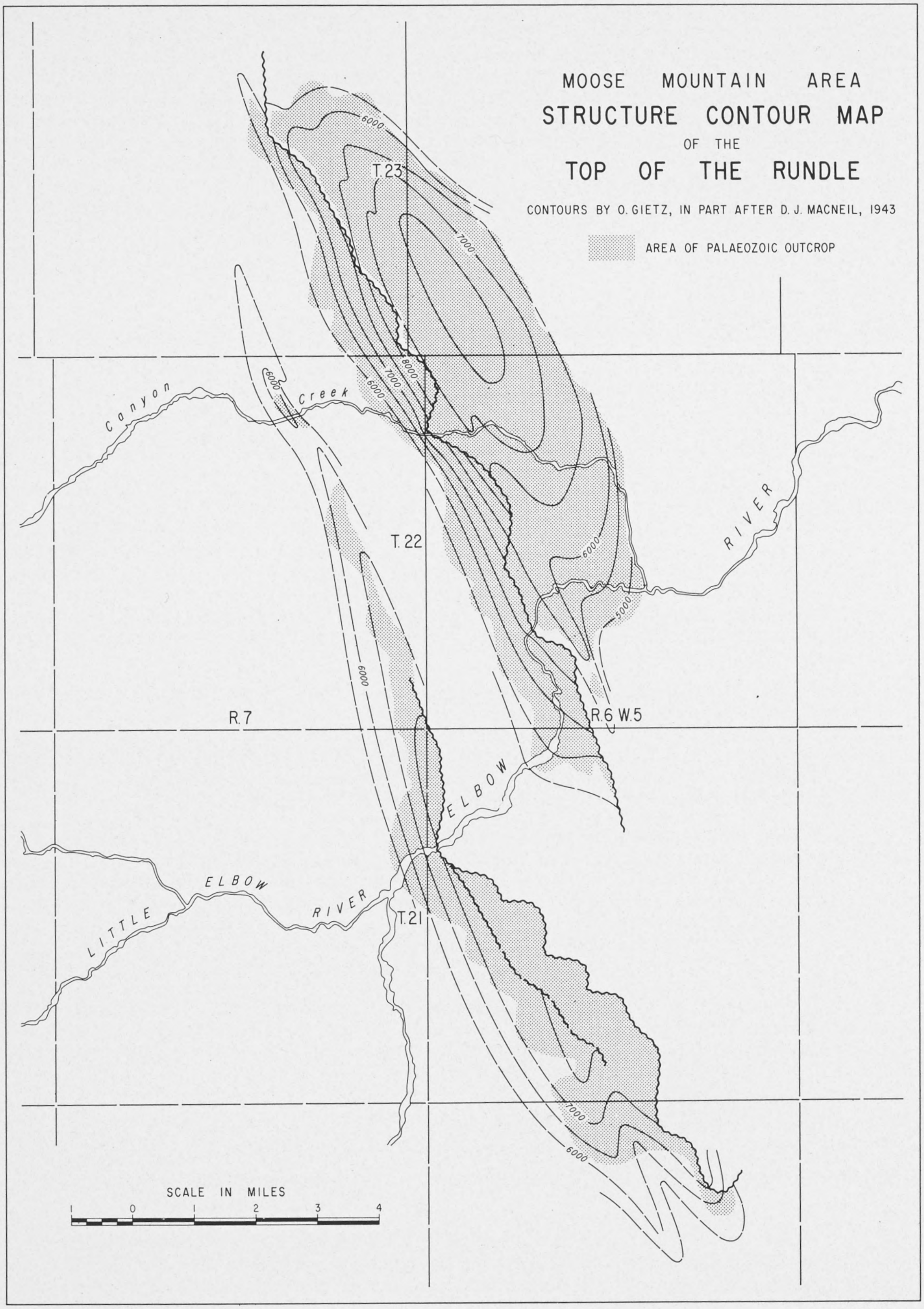

MOOSE MOUNTAIN AREA
STRUCTURE CONTOUR MAP
OF THE
TOP OF THE RUNDLE
CONTOURS BY O. GIETZ, IN PART AFTER D. J. MACNEIL, 1943
AREA OF PALAEOZOIC OUTCROP
T.23
T.22
T.21
R.7
R.6 W.5
Canyon Creek
RIVER
ELBOW
LITTLE ELBOW RIVER
6000
7000
8000
5000
SCALE IN MILES
1 0 1 2 3 4

FIGURE 5

From well data in the south end of the Turner Valley field the displacement of the top of the Rundle by the Turner Valley fault is known to be in the order of two miles. On the surface in the same locale the fault, which is mapped as the Turner Valley fault, dies out. These two facts are not consistent and suggest that the Turner Valley sole fault is not exposed and that the fault mapped at surface is merely an imbrication. Since no evidence of thrust faulting exists at surface to the east of the Turner Valley fault, we assume that the motion on the sole thrust is dissipated by crumpling and minor faulting of the younger rocks. This is probably the general case along the east edge of the Foothills where fault dissipation produces a structurally thickened wad of sediment occupying the space between the regional Plains strata, the east-dipping limb of the Alberta syncline and the overall west dip of the Foothills structures.

Conclusions

The surface geology of the Moose Mountain area provides data from which several conclusions were drawn. The writers do not suggest that these have been irrefutably proven, but rather that the evidence strongly suggests that the conclusions are correct.

The McConnell thrust is flat-dipping at least as far west as the Bourgeau thrust. The various lesser thrusts in the hanging wall are probably imbrications which are all connected to the McConnell. Some of these appear to die out laterally through transfer of motion from one fault to another.

In the instance of the Dyson Mountain thrust and related structures the following sequence is established:

1 Folding.

2 Development of the major sole fault and motion thereon.

3 Folding of the sole fault and of the plates above and below.

4 Development of an imbrication from the sole fault.

5 Motion on the imbrication inducing folds in the hanging-wall rocks.

This sequence is not visualized as a series of separate episodes but rather it is thought that folding and faulting operated simultaneously with one or the other mode of deformation being dominant at any specific time. The relationships across the Fullerton tear indicate that folding and faulting operated simultaneously in that area.

The Turner Valley sole fault is believed to die out upward in a crumpled zone. Only a relatively minor imbrication is present at the surface. This phenomenon may be common elsewhere in the Disturbed belt.

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NISKU LITHOFACIES OF ROCKY MOUNTAINS, ALBERTA [1]

G. E. HARGREAVES [2]

Abstract

The Nisku formation of the Winterburn group of Upper Devonian age is mapped throughout a portion of the Alberta Rocky Mountains. The area studied extends from the Moose Mountain area in the south to the Smoky River area in the north. Based on lithological similarities to well established lithofacies types of the Plains area, the formation is mapped into approximate areas of five predominant informal rock types as follows: dolomite, porous in part; dolomite, silty and argillaceous; limestone and dolomite, interbedded; limestone; shale and limestone, interbedded. All rock types are considered to be the same approximate age, but an exception is noted in that the upper part of the Nisku shale and limestone facies, which has previously been included with the Alexo, may be of post-Nisku age in the southeast part of Jasper National Park.

The Nisku lithofacies map is based on 53 measured outcrop sections and 18 well sections. A summary of selected outcrop sections is tabulated.

Introduction

At least as early as the summer of 1952, field geologists of several oil companies were applying the name Nisku to rocks of the upper part of the Mount Hawk formation in the Jasper area. At Roche Miette, the upper 105 feet of the Mount Hawk (type section, de Wit and McLaren, 1950 forms a grey limestone member which is cliff-forming and thickens to at least 170 feet along strike. By tracing this member, together with the overlying Alexo and the underlying Ireton, through to the normal Nisku dolomite facies in the Hummingbird area, Twp. 36, Rge. 16, W5M, (Pl. I and Fig. 1) a widespread correlation of different lithologies of approximately equal age is established; these various facies constitute the Nisku formation of this report. It comprises a shale and limestone facies over an extensive area within southeast Jasper National Park. Correlation of Nisku beds in the northern part of Jasper Park and beyond to the Smoky River is possible although somewhat less satisfactory. The main purpose of this paper is to present a lithofacies map (Fig. 1) of the Nisku from the Moose Mountain area of the southern Alberta Rocky Mountains to the Smoky River area in the north.

To provide facies details and to establish the correlation, summarized measured outcrop sections are presented in Figure 2, in order of township, range and approximate section.

Previously published reports of the Jasper area by de Wit and McLaren (1950), and McLaren (1955a), have included the above-mentioned Nisku shale and limestone facies (plus sandstone at Morro Peak) with the overlying Alexo formation. Taylor (1957 and 1958), noted the diachronous boundary between the Alexo and the Mount Hawk formations.

In the Bow Valley area, the Nisku includes the combined Arcs and all or most of the Grotto member of the Southesk formation of Belyea and McLaren (1957). A standard surface section by Taylor (1957) near the Loder Lime plant requires only slight modification to be compatible. The top 58 feet of Taylor's Leduc is included with the Nisku, the underlying 47 feet of argillaceous and silty beds is assigned to the Ireton.

In the Hummingbird area (Sec. 2, Twp. 36, Rge. 16, W5M, Fig. 2) the Nisku is easily recognized as a 190 foot dolomite unit, underlain by a 45 foot covered interval assumed to be part of the calcareous shale of the Ireton. A thin tongue of Ireton extends an unknown distance over the broad Leduc carbonate build-up to form a silty, argillaceous marker separating the Nisku from the Leduc. Where the Ireton formation is absent in areas of high Leduc build-up, the base of the Nisku has been arbitrarily picked at the top of an argillaceous zone within, or at the base of, a brown coral member (upper Grotto of Belyea and McLaren, 1957 a and b).

The field work upon which this paper is based was carried out by the writer and other Canadian Superior Oil of California geologists during the summers of 1951 and 1952. Sections were not described in detail; measurements by a 5 foot Jacob's Staff were sometimes necessary, and although obvious faulted sequences were avoided, the Nisku shale and limestone facies, in particular, might well contain some undetermined fault thickening. The application of the Edmonton area Devonian terminology, as defined by Imperial Oil Ltd. geologists (1950), was found to be more satisfactory both in the field and in the office than the prevailing mountains terminology of de Wit and McLaren (1950), and so was used throughout the entire area studied.

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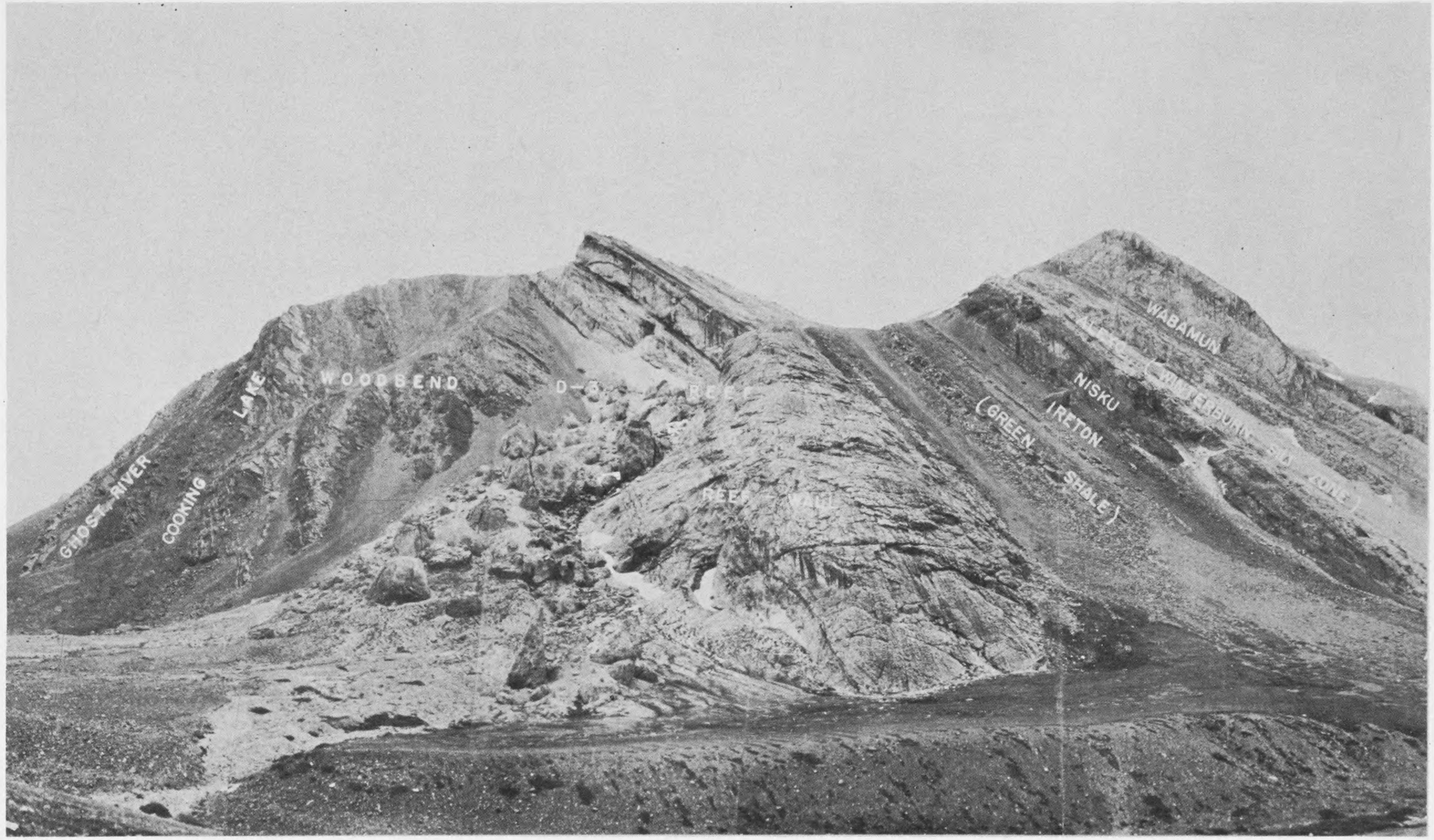
1 Published with the permission of Canadian Superior Oil of California, Ltd.

2 Geologist, Canadian Superior Oil of California, Ltd. The writer is indebted to L. V. Illing and G. E. Thomas for constructive comments.

PLATE I



Headwaters of a north fork of Hummingbird Creek (Sec. 2, Twp. 36, Rge. 16, W5M.), panoramic view looking southeast at the Upper Devonian sequence. The Leduc reef changes to an argillaceous facies immediately north of this exposure. The Nisku formation continues northward without facies change for at least 4 miles; at this locality it is comprised of 95 feet of dark grey-brown fossiliferous dolomite overlain by 95 feet of light grey non-fossiliferous dolomite with poor, vuggy porosity.

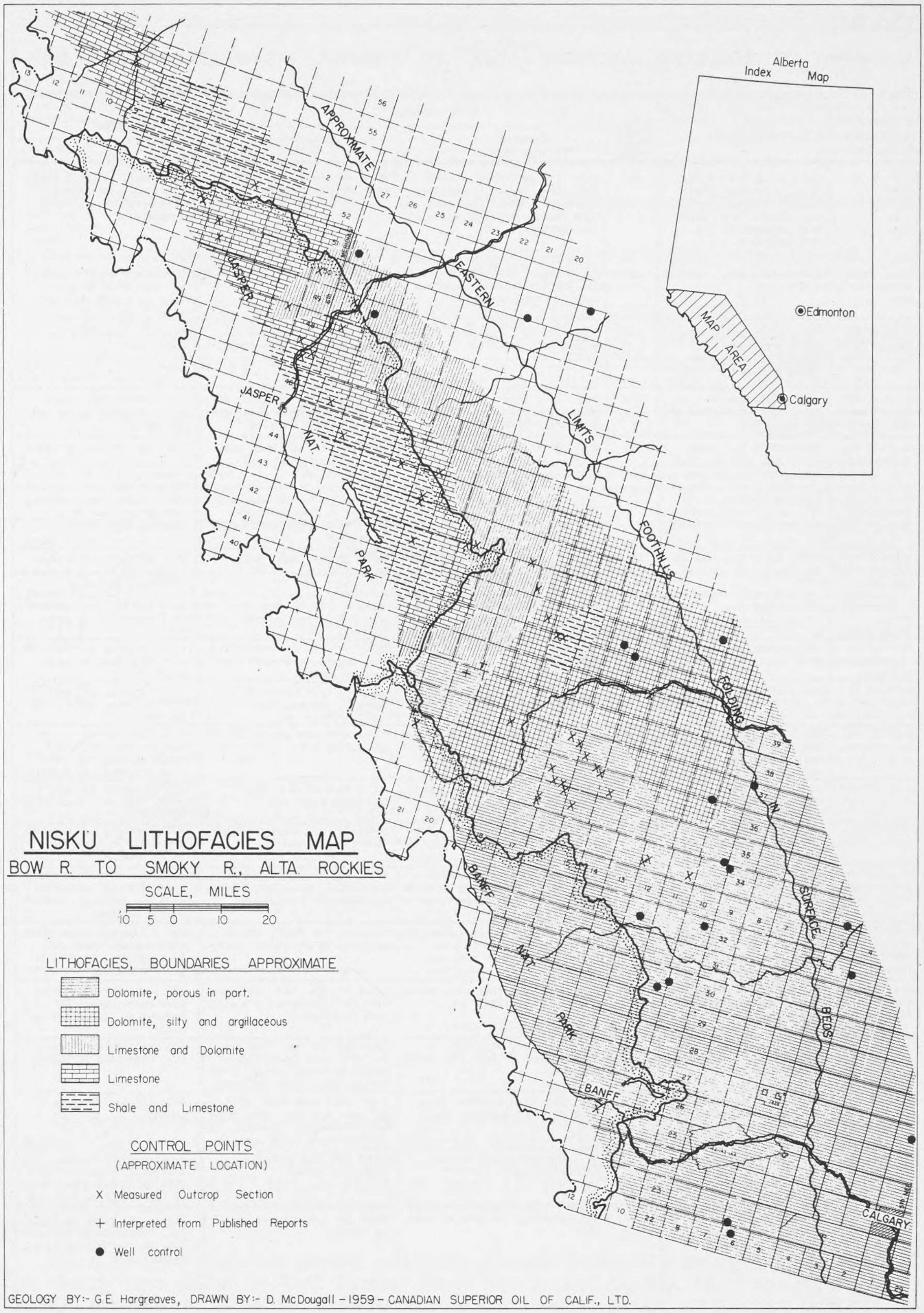

NISKU LITHOFACIES MAP
BOW R. TO SMOKY R., ALTA. ROCKIES
SCALE, MILES
10 5 0 10 20
LITHOFACIES, BOUNDARIES APPROXIMATE
Dolomite, porous in part.
Dolomite, silty and argillaceous
Limestone and Dolomite
Limestone
Shale and Limestone
CONTROL POINTS
(APPROXIMATE LOCATION)
X Measured Outcrop Section
+ Interpreted from Published Reports
● Well control
Alberta
Index Map
MAP AREA
Edmonton
Calgary
APPROXIMATE EASTERN LIMITS FOOTHILLS FOLDING IN SURFACE BEDS
JASPER
JASPER NAT. PARK
BANFF NAT. PARK
BANFF
CALGARY
GEOLOGY BY:- G.E. Hargreaves, DRAWN BY:- D. McDougall - 1959 - CANADIAN SUPERIOR OIL OF CALIF., LTD.

FIGURE 1

SUMMARY OF SELECTED SECTIONS USED TO COMPILE NISKU LITHOFACIES MAP

LOCATION Approximate Sec. Twp. Rge.	ALEXO Overlying Beds	NISKU SUMMARY			IRETON Underlying Beds
		Total Thick-ness	Dominant Rock Type	Associated Rocks	
25-24-11 W5 South Mt. Rundle.	350'; silty ls., silty dol., siltstone, basal 19 siltstone and sandy sh. May be fault thickened (changes in dip with breccia)	270'	Dol., lt. gy., fine - coarse xln., med. bedded to massive, upper 100' finely laminated, some organic detrital bands, poor porosity.	Basal 20' is dk. gy. fine xln. with abundant corals.	20'; brn., slightly argil. silty dol., arbitrarily considered to be Ireton equivalent.
11-34-11 W5 Limestone Mtn.	150'; silty dol., covered in part	120'	Dol., vuggy, dk. brn.-gy., fine xln., thick to med. vague bedding, covered in part.	None.	350' plus; argil. nodular ls. underlain by green clay sh., base covered.
7-34-12 W5 Timber Creek	200'; silty dol., dolomitic ss., basal 33' largely covered, some dolomitic ss.	190'	Dol., lt. gy., fine-med. sugary, patchy poor porosity.	Basal 25' is brn. fine xln. to sugary dol., very fossiliferous.	Directly underlain by Leduc reef.
17-35-15 W5 Second Range Gap, Ram R.	190'; siltstone, sh., ls., basal 15' interbedded sh. and silty dol.	160'	Dol., gy., fine xln. to sugary, poor to fair inter-xln. porosity, non-fossiliferous	An 85' zone in middle of Nisku of dk. brn. gy. v. fine xln. dol., v. fossiliferous.	120'; silty dol. argil. dol., nodular ls. and sh. to Leduc.
18-35-16 W5 Whiterabbit	230'; silty ls., some silty dol. and dol. breccia, sandy sh. at base.	290'	Dol., v. dk. gy., sugary, abund. calcite filled vugs of organic? origin, good porosity in part.	Upper 12' lt. gy. med. xln. dol. with original vugs calcite filled.	340' est. to top of Leduc.
36-35-16 W5 Hummingbird, Main Branch	155'; siltstone, silty ls., silty dol., basal 10' dolomitic siltstone.	215'	Dol., lt. to dk. gy. med. xln., some poor vuggy porosity, non-fossiliferous.	Dol., blk., v.fine xln. to sugary, v. fossiliferous, forms a 90' band toward base of section.	154'; silty argil. dol., nodular ls. and sh., underlain by Leduc.
9-36-14 W5 Ram Gap, Ram River	227'; silty dol., silty ls., basal 36' covered.	175'	Dol., lt. gy., fine xln., massive, patches with good inter-xln. porosity.	Basal 50' dk. brn. dol., fossiliferous.	29'; assumed Ireton some Atrypa and sh. in scree. Underlain by Leduc.
35-36-15 W5 South Cripple Ck.	180'; silty dol., basal 15' siltstone and covered	160'	Dol., lt. gy., med. xln., thin to med. bedded, generally tight.	Basal 30' is dk. brn. fine xln. dol., fossiliferous, tight.	90'; nodular ls. and green sh., underlain by Leduc reef.
2-36-16 W5 N. Hummingbird, South Side.	180'; siltstone, silty dol., basal 45' covered.	190'	Dol., v. dk. gy., v. fine xln., fossiliferous, tight.	Upper 95' lt. gy. med. xln.-semi sugary, some poor fine vuggy porosity.	210'; nodular ls. and green sh., underlain by Leduc reef.
17-36-16 W5	115'; silt and dol.	200'	Dol., v.dk. gy., fine-med. xln., fossiliferous, tight.	Upper 95' gy. fine xln. to suggary, massive, non-fossiliferous dol.	195'; nodular ls. and sh., to thick Reef Equiv. blk. sh. and ls.
20-36-21 W5 Mt. Coleman, West.	220'; silty dol., some dol. breccia, basal 50' cyclical dol. and silty dol.	165'	Dol., dk. gy.-brn., fine xln., med. bedded to massive, abundant corals, porous.	A 45' unit near middle of lt. gy. porous dol.	435'; nodular ls. in sh. matrix with blk. chert, basal 140' dk. gy. brn. v. fine xln. dol. to Duvernay?
27-37-16 W5	140'; silty dol., basal 25' shaly silt.	150'	Dol., brn. fine xln. to sugary, vuggy in part, fossiliferous, chert nodules.	Upper band of med. xln. generally tight dol.	295'; nodular ls. and green clay sh., over thick Duvernay.
21-37-18 W5 Cline, North	180'; silty dol., basal 15' soft khaki sh. and sandy dol.	190'	Dol., dk. gy., fine xln., fossiliferous in part, cherty, tight.	Basal 45' gy. dol. with some fine vuggy porosity.	408'; nodular ls. and sh., dolomitic at top, over thick Duvernay.
36-39-14 W5 Brazeau Gap, North Sask.	180'; siltstone, silty dol., basal 25' argil. silty dol.	160'	Dol., gy. to dk. gy., thick vague bedding, grading to thin-bedded and silty in part.	Basal 65' dk. gy. to blk. argil. ls., thin rubbly bedded, abundant brachiopods.	720'; green-gy. clay sh.; upper 100' ls. and dol. with sh. partings. dolomitic in part.
32-40-17 W5 Wapiabi River, Bighorn Rg.	175'; silty ls., dolomitic silt, basal 115' silty dol., med. bedded.	215'	Dol., dk. gy. to blk., fine xln, silty argil., thin to poorly bedded, blk. chert near base.	95' net, blk. calc. sh. in units up to 50' thick, platy.	215'; v. argil. dol. chert, thin bedded, basal 110' green-gy sh., covered in part to Leduc
14-41-18 W5 Cirque, Bignorn Rg.	155'; silty dol., thin bedded and buff weathering at base.	180'	Dol., dk. gy., fine xln., silty, argil., thin bedded.	Upper 20' gy., med. xln. dol. with fair porosity, a 5'silty band in middle.	180'; nodular argil. dol. with chert, basal 40' assumed sh. (covered) to Leduc.
7-42-18 W5 Blackstone River, Bighorn Rg.	160'; silty dol., silt, porous dol., basal 45' silty dol.	145'	Dol., lt. gy., med. xln. to sugary, poor to fair fine vuggy porosity.	Upper 50' lt. gy. fine xln. ls. with much fossil-fragmental material, basal 27'dk. brn-gy. dol., fossiliferous.	5'; khaki-colored argil. dol. underlain by Leduc.
32-42-21 W5 Cairn and Southesk R.	235'; v. silty dol., silt pelletoid ls., basal 5' green sh.	245'	Ls., tan, fine grained, pelletoid in part, massive, tight.	A 90' unit near base of lt. gy, med. xln. dol. with porosity. Basal 25' covered, probably brn. coral dol.	Directly underlain by Leduc.
21-42-23 W5 Southesk Lake	200'; ss. and siltstone.	150'	Sh., green-gy, clay to blk. fissile at base, calc.	Upper 100' has common v. argil. ls. bands.	890'; top 25' dolomitic siltstone, remainder sh. with ls. nodules and bands in upper half to Duvernay.
4-44-23 W5 Mt. Meda	90'; silty dol. and ss. Alexo is 165' at next mountain to south-east.	200'	Sh., green-gy. to blk. at base, calc.	Upper 50' has common nodular ls. bands.	Upper 115' cliff of argil. ls., underlain by ls. and blk. sh. to Cooking Lake build-up.

LOCATION Approximate Sec. Twp. Rge.	ALEXO Overlying Beds	NISKU SUMMARY			IRETON Underlying Beds
		Total Thick-ness	Dominant Rock Type	Associated Rocks	
33-44-24 W5 Rocky Forks	170'; silty ls. and calc. ss.	235'	Sh., blk., calc., soft, fossiliferous.	Upper 100' a dk. gy. fine xln. ls. with gy. sh. partings.	600'; interbedded gy. sh. and ls., grades to very dk. gy. to base.
2-45-23 W5 Mt. MacKenzie South-East.	75'; silty ls. and dolomitic ss.	220'	Ls., tan-gy., litho. to med. grained, pelletoid in part, thick evenly bedded, thin vuggy bands.	Upper 6' vuggy dol.	0 - 120'; green-gy. sh. to Leduc.
8-45-26 W5 Medicine Lake (Beaver Ridge)	205'; ss., silty ls., basal 65' nodular ls.	355'	Sh., dk. gy., platy to rubbly, basal 30' blk. fissile.	Upper 55' interbedded silty ls. and calc. sh.	600'; thin dolomitic silt, upper calc. sh. with ls. bands, lower fissile sh. to Duvernay.
9-46-27 W5 Merlin Pass	205'; siltstone, silty ls basal 55' argil. nodular ls.	340'	Ls., v. dk. gy., argil., in part finely interbedded with more argil ls.	Basal 125' sh., v. dk. gy., platy, grading to blk. fissile at base.	260' plus; (base not exposed) dolomitic ss., interbedded ls. and sh., green sh.
10-47-1 W6 Morro Peak	265'± calc. fine ss. with silty ls. bands, basal 10' covered.	?	Nodular ls. and sh., silty ls., thinly interbedded. Thickness of 400' probably increased by fault.	Includes an 80' ss. unit near base underlain by 70' covered interval traced along strike to blk. fissile sh.	350'; ls. and gy. sh. thinly interbedded ribboned appearance, possible fault at base to covered interval
33-47-1 W6 Mt. Greenock	100'; argil. silt and silty ls.	150'?	Ls., dk. gy., fine xln., massive to med. bedded with abundant poorly preserved corals and alge.	None. This section faulted thus thickness in doubt.	Interbedded ls. and shaly ls., not measured.
29-48-27 W5 Roche Miette	245'; siltstone, silty dol. and silty ls.	170'	Ls., dk. gy., fine xln., thick bedded, scattered vugs, coral bands near top, a middle unit thickens and thins along strike.	Basal 25' is blk. argil. ls. interbedded with blk. dolomitic sh.	440'; interbedded ls. and dk. gy. sh. to thick Duvernay.
34-48-2 W6 Mt. Cumnock	90'; upper thin ss., thick bedded lt. gy. fine xln. ls. with silty interbeds.	210'	Ls., gy. to dk. gy., fine xln., massive to vaguely med. bedded, tight, rare corals.	Approx. 90' net fine-med. xln. dol. as interbeds, tight.	400' plus; (base not exposed), argil. ls. and interbedded shaly ls.
28-49-27 W5 Boule Roche	100'; silty ls., siltstone, silty dol., vuggy ls. basal 15' silty argil ls.	285'?	Dol., gy. and dk. gy., fine sugary, argil. calc., thick bedded, common corals and algae.	Upper 110' v. dk. gy. ls., argil. in part, massive, beds lensing from 1'-21' with abundant corals.	Not known, faulted and covered, upper part 124' argil. silty ls. with some blk. sh. to thick Duvernay.
17-50-1 W6 Moosehorn, Bosche Range	230'; thin ss. at top, silty ls. and dol., 40' porous dol. near base; basal 15' covered.	280'	Ls., gy. to blk. fine xln., massive to med. poorly bedded, rare corals, pelletoid in part.	With 80' net interbedded dol., dk. gy. mud. sugary, abundant corals.	440'; nodular ls. and sh. grading to dk. gy. sh. at base to thick Duvernay.
15-50-5 W6 Mt. Simla	54'; silty dol., argil. ls., basal 20' covered but in part a red clay sandy sh.	155'	Ls., dk. gy., fine xln. argil. med. bedded, rare brachiopods.	Basal 75' tan lithographic ls. pelletoid, fossil fragmental, distinctly thick bedded.	60'; ls. as above with common thin sh. interbeds to Woodbend ls.facies.
33-50-5 W6 Ancient Wall	65'; silty ls. and covered interval which corresponds to red sh. horizon at 15-50-5 W6.	165'	Ls., dk. to med. gy., fine to med. grained, med. bedded, common Amphipora in part.	None.	Underlain by a 6' covered interval, arbitrarly separated from underlying Woodbend ls. and vuggy dol.
14-51-6 W6 Glacier Pass, South	55'; silty dol., ls. conglomerate, red and green sh.	95'	Ls., dk. gy., argil. grading to nodular ls. and gy.-green clay sh.	Top 17' tan lithographic ls. pelletoid, fossil detritus.	80'; calc. gy.-green clay sh., to Leduc, vuggy dol.
22-51-6 W6 Glacier Pass, North	47'; green sh., silty ls. Disconformable with overlying Wabamun.	120'	Ls., dk. gy.-brn., fine grained med. bedded, with argil. ls., thin bands of fragmental ls.	Basal 40' nodular ls. and gy.-green sh.	420'; sh., fore-reef breccia and argil. ls. to Cooking Lake build-up.
1-52-7 W6 Brewster's Wall.	55'; covered, red and green sh. in part.	110'	Ls., gy.-dk. gy., fine xln., slightly argil., massive.	None.	Calc. green sh., only 20' exposed.
5-54-8- W6 Winnifred Pass.	80'; silty ls., red and green sh.	85'	Ls., dk. gy., fine-med. grained, pelletoid in part, abundant organic detritus in basal beds.	A middle 27' green gy. sh. unit, partly covered.	620'; sh., argil. ls., small ls. bioherms, to Duvernay.
6-55-9 W6 Smoky River	33'; silt, silty ls., basal 4' green clay sh.	?	Ls., gy. to dk. gy., fine to coarse detrital, distincly thick bedded.	None	None. Nisku not separable, assumed to be part of a 395' ls. unit with the Woodbend ls. facies.

FIGURE 2

Good correlational logs were run through the dolomite facies of the Nisku at Shell Burnt Timber 6-26 (Lsd. 6, Sec. 26, Twp. 32, Rge. 10, W5M). The upper fault slice of "Palaeozoics" contains Nisku, from 6310 to 6460 feet, of the dark brown type. A second slice contains Nisku, from 14,360 to 14,555 feet, in which the upper 125 feet is the light grey medium crystalline type, and the basal 70 feet is dark brown, fine crystalline, with white inclusions, possibly coral fragments.

Good reservoir beds are present within the dolomite facies and a natural gas discovery well has already been drilled at Shell Panther River No. 1 (Lsd. 5, Sec. 19, Twp. 30, Rge. 10, W5M). Another important aspect of this facies is that to some degree, its presence indicates the proximity of the more important underlying Leduc formation.

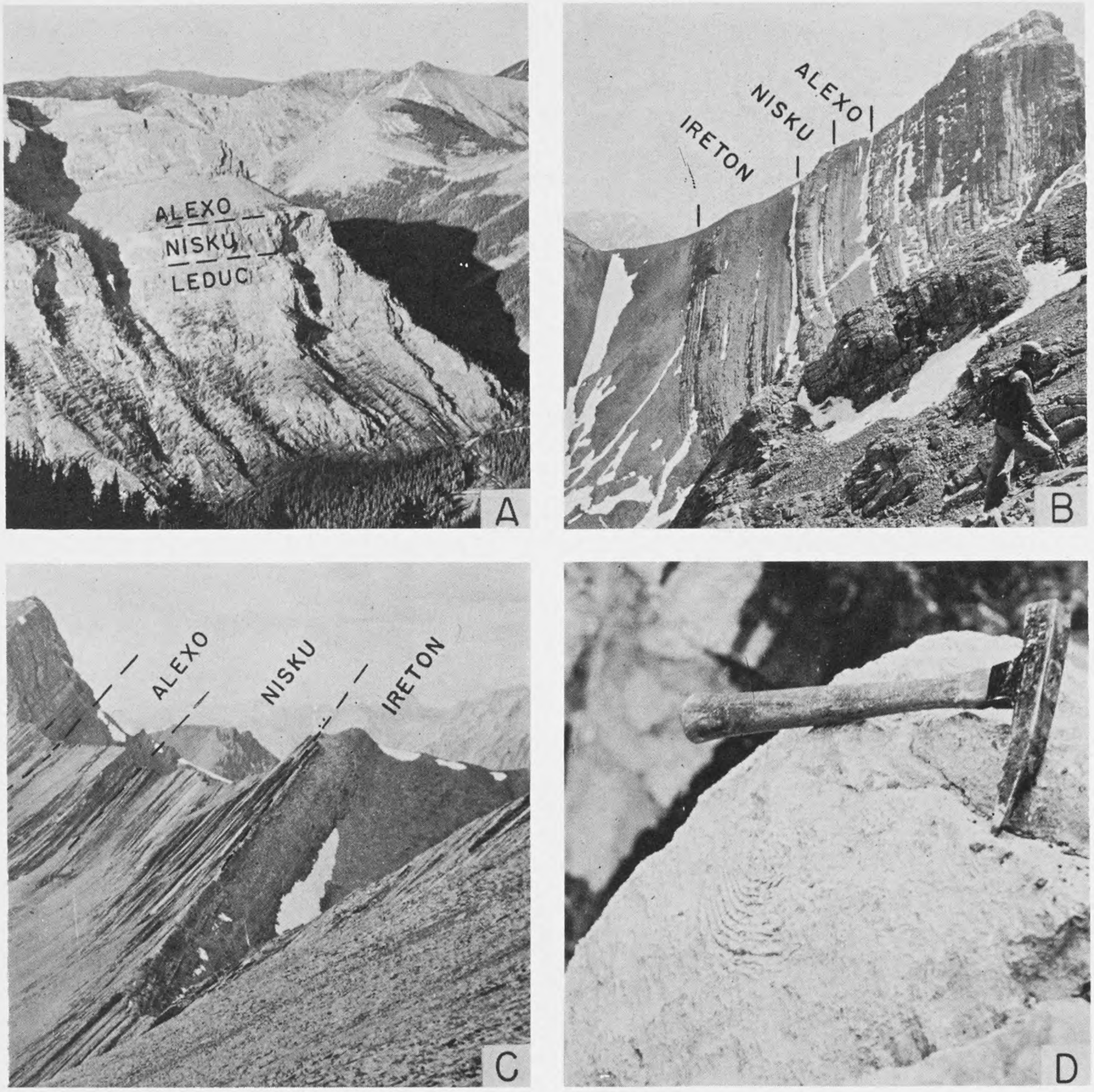


PLATE II

A Ram Range, south of Clearwater River, looking east across Timber Creek to exposures at Sec. 7, Twp. 34, Rge. 12, W5M. The Nisku here comprises an upper 165 foot cliff of light grey medium sugary dolomite with patchy poor porosity, underlain by 25 feet of recessive weathering, brown, fossiliferous dolomite.

B Roche Miette, east side; a view looking southeast at a locality in Sec. 29, Twp. 48, Rge. 27, W5M illustrating the cliff-forming Nisku limestone with large scale lensing evident in background toward base of slope.

C Mount Meda (Sec. 4, Twp. 44, Rge. 23, W5M); view looking northwest along the top of a cirque; the top of the dip-slope is the thin basal black shale facies of the Nisku, grading upward into nodular limestone and green-grey shale. The nodules are concentrated in bands giving the strongly bedded appearance. Total Nisku thickness is 200 feet.

D Algal structure; Mount Simla (Sec. 15, Twp. 50, Rge. 5, W6M), showing one of the many algal forms common to the Nisku of this area. This example is in light grey, pelletoid limestone which weathers to a rasp-like surface.

Overlying and Underlying Beds

As used in this paper, the underlying Ireton formation is intended to be the lithic analogue of the Ireton of the west and central Alberta Plains. The lower contact of the Nisku is commonly marked by a thin rusty-weathered, silty, argillaceous dolomite which is included with the Ireton. An aid to correlation in some areas is the relatively cliff-forming interbedded silicious dolomite and fossiliferous shale sequence at the top of the Ireton. In broad concept, this interpretation of the Ireton would exclude any overlying carbonate members of the Camrose type, but would include argillaceous strata of the lower Delia or Grotto type.

The Alexo formation is herein restricted as closely as possible to the Graminia, Blueridge and Calmar time-equivalent, and together with the underlying Nisku formation comprises the Winterburn group.

Only minor changes of the original Alexo type section at Brazeau Gap (Sec. 36, Twp. 39, Rge. 14, W5M) are required to be consistent with the usage of this paper. These are the omission of the top 53 feet of brecciated limestone which is interpreted to be part of the overlying Palliser formation, and the inclusion of the top 20 feet of the Mount Hawk as suggested by McLaren (1955a) in a later treatment.

As thus restricted, the Alexo comprises interbedded silty or sandy limestone and dolomite, silty breccia, sandstones, minor shale beds, with local cleaner limestone or dolomite lenses which sometimes have algal growths and corals. Porous beds are rare. Over the wide area which is underlain by the Nisku dolomite, the base is clearly defined by a relatively thin green sandy shale or argillaceous sandstone comparable to the Calmar formation. This basal unit is recessive weathering. In areas of Nisku shale and limestone facies the base of the Alexo is not so clearly defined, however red and green sandy shales similar to the "Red Beds" at the Leduc type section were trenched at several localities north of Jasper. The exclusion of thick shale sequences, such as those at Beaver Ridge near Medicine Lake, from the Alexo is lithologically compatible with the formation as described in its type section by de Wit and McLaren (1950) at the Brazeau Gap (approximate locality Sec. 36, Twp. 39, Rge. 14, W5M, this paper). In areas of Nisku dolomite facies, the Alexo-Nisku contact is sharp and probably disconformable. Possible pre-Alexo erosional channels up to 5 feet deep were seen in the top of the Nisku.

Nisku Lithofacies Types

nisku dolomite facies

The Nisku of the south half of the area mapped comprises two main types of dolomite. These are a dark brown coralliferous dolomite which predominates at the base, and an upper light grey non-fossiliferous dolomite which predominates at the top. The two types may be interbedded, or one type may completely replace the other. Both types are mapped together as "Dolomite, porous in part" in Figure 1.

The brown dolomite contains abundant coral and *Amphipora* debris. These white organic remains are commonly broken into fragments which are concentrated in bands and large lenses, as if by current action. The enclosing rock is a fine to very fine sugary dolomite with variable amounts of dark brown, bituminous (?) and argillaceous interstitial material. The dark weathered surface commonly exhibits good vuggy porosity but inspection of a fresh surface usually shows this rock type has no visible porosity under low magnification.

Massive, white-weathering cliffs characterize the light-grey dolomite type (Pl.II.a). Grain size varies from fine to coarse, with frequent alternations of the two that produce a finely laminated weathered surface similar to a sandstone. Although these laminations may be crossbedded, this dolomite usually has flat, even bedding planes that 'come and go'. The weathered surface commonly has a deeply pitted porous appearance, but large vugs were rarely observed within this rock. Scattered zones of poor to fair intergranular and fine vuggy porosity were seen in most exposures; none had continuous porosity throughout.

The thickest Nisku dolomite sections are predominately of the light grey type. Commonly the upper 20 to 40 feet of Nisku dolomite is tight, possibly because of pre-Alexo emergence with resultant infilling of the original pore spaces.

NISKU SILTY AND ARGILLACEOUS DOLOMITE FACIES

A less interesting reservoir facies of silty and argillaceous dolomite comprises most of the Nisku formation in the North Saskatchewan River area (Fig. 1). This lithofacies is undoubtedly reflecting a slightly deeper water environment and the absence of the underlying Leduc reef. The typical lithology, as seen at Brazeau Gap, North Saskatchewan River (Sec. 36, Twp. 39, Rge. 14, W5M) is a dark grey dolomite, argillaceous and silty in part, with a basal shaly limestone. Considerable variation in gross lithology is apparent in the Cline area (Sec. 21, Twp. 37, Rge. 18, W5M) where the usual tight, slightly argillaceous dolomite changes laterally to a grey vuggy facies. Rapid local variations are expected within the entire area mapped as "Dolomite, silty and argillaceous" in Figure 1.

NISKU LIMESTONE AND DOLOMITE FACIES

Peripheral to much of Jasper National Park, a number of Nisku sections are comprised of interbedded limestone and dolomite; they are grouped as an informal transitional unit on the lithofacies map. Conjectural mapping along the east side of Jasper Park forms a logical separation, in this area of sparse control, of the dolomite of the Plains area from the limestone facies closer to, and within the National Park. The laterally equivalent limestone beds have much the same bedding, weathering color and cliff-forming properties, as the equivalent dolomite bands, but they are commonly lithographic. Compared to the dolomite facies, the weathered surface of the limestone shows fewer vugs, but may be laminated and very finely cross-bedded with an etching of coarser detrital grains. Like the light grey dolomite counterpart, the limestone beds are usually nearly devoid of macroscopic organic remains, except for probable algae; also the strong evenly bedded appearance when seen from a good distance, becomes vague and discontinuous upon close inspection. Porosity within the limestone bands is confined to rare thin beds containing very fine vugs, but the interbedded dolomite is commonly porous.

NISKU LIMESTONE FACIES

In the Jasper area, (Fig. 1) the limestone facies of the Nisku is commonly dark grey, with scattered fine to medium grains of skeletal origin. On Boule Roche (Sec. 28, Twp. 49, Rge. 27, W5M) and Roche Miette (Pl.II.B, Sec. 29, Twp. 48, Rge. 27, W5M, Fig. 2), prominent local "reefing" from a bedded middle member to a thicker massive unit takes place. This same feature is present at Cardinal Mountain and Mount Cinquefoil.

A preliminary study of thin-sections of the limestone indicates that a wide variety of energy levels is present. The Type I high-energy environment of Folk (1959), is illustrated by the closely packed coarse to very coarse intraclasts with sparry calcite matrix (Pl.III.A and B). This type of limestone has been termed "pelletoid" in the Nisku summary compiled in Figure 2; it grades into one with fine intraclasts, (Pl.III.D). A lower energy level, where currents were not strong enough to winnow away the microcrystalline ooze, is indicated by much of the limestone, (Type II) which has a matrix of carbonate mud and fine skeletal debris, (Pl.III.C). On the basis of a very limited number of thin-sections, it is apparent that Type II is more readily dolomitized than Type I. Both the above groups are interbedded with low energy lithographic limestone.

Algal growths are apparent in the cleaner limestone areas as crudely concentric laminated "cabbage-head" stromatolites and irregular banded rocks which in thin-section have an orientated fibrous texture (Pl.III.B). According to McLaren (1955b), these macrostructures may be matched by recent laminated sediments trapped by blue-green algae on emergent mud flats in Florida Bay.

NISKU SHALE AND LIMESTONE FACIES

In the Southesk Lake-Medicine Lake area of Jasper Park the entire Nisku stratigraphic interval is represented by shales with some nodular and banded argillaceous limestone interbeds (Fig. 1). From Southesk Lake (Sec. 21, Twp. 42, Rge. 23, W5M) to Merlin Pass (Sec. 9, Twp. 46, Rge. 27, W5M) a black calcareous shale forms a prominent marker bed within the basal part of the Nisku (Fig. 2). This shale, which varies from 15 to 33 feet in thickness, is non-fossiliferous but is overlain by grey-green shale which contains bands rich in brachiopods. This grey-green shale contains an increasing number of limestone bands and nodules towards the top, Pl.II.C). Except for its thickness (approximately 150 feet), the shale and nodular limestone facies closely resembles the Ireton in gross lithology. At Medicine Lake, Beaver Ridge, (Sec. 8, Twp. 45, Rge. 26, W5M) the combined shale units, (300 feet thick), are included with the Alexo by McLaren 1955a) on the basis of the age of its brachiopod fauna.

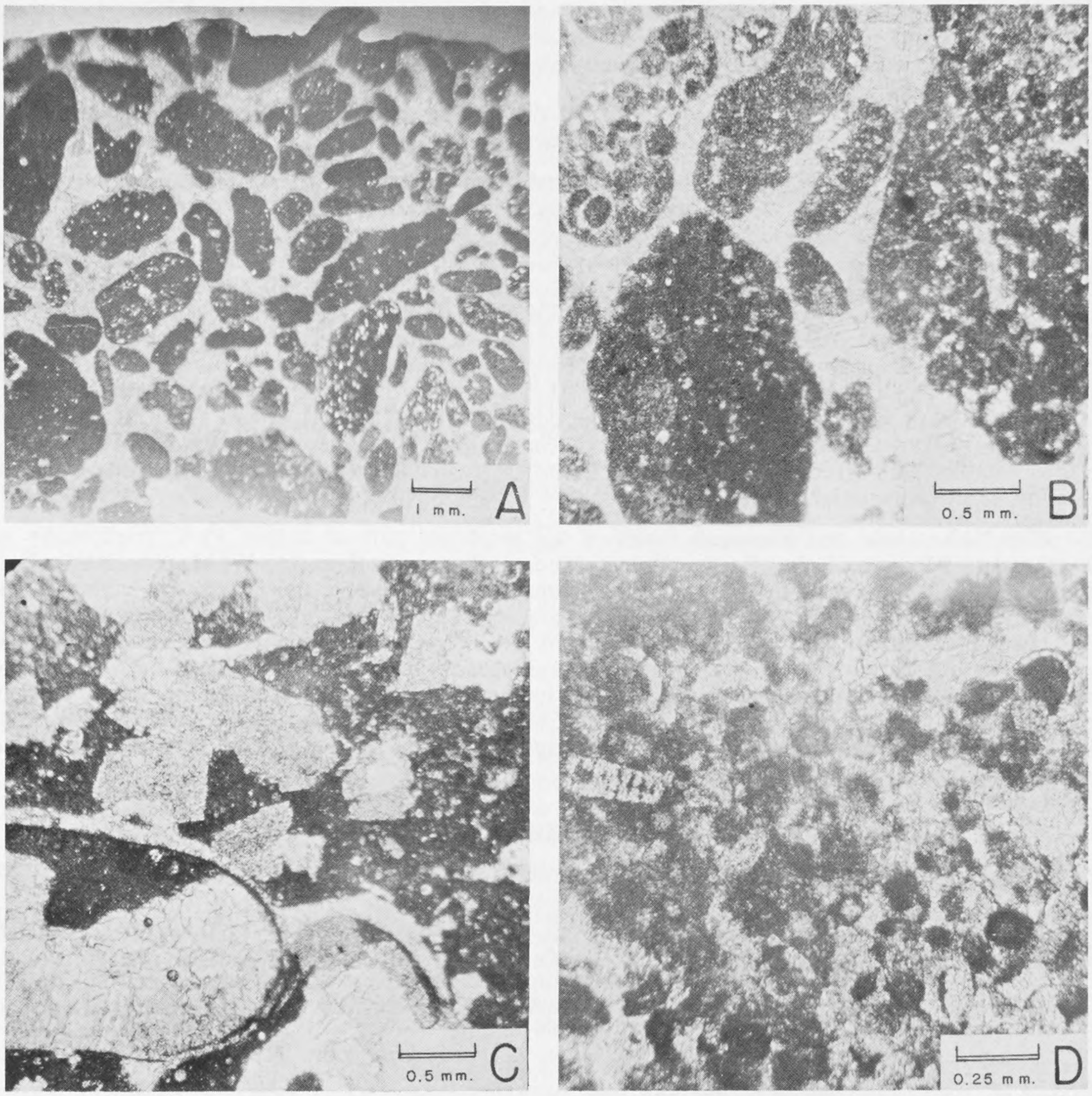


PLATE III

A Light grey limestone 20 feet from the top of the Nisku at Mt. MacKenzie. Note the coarse to very coarse grains or intraclasts, some with bedding, in a sparry calcite cement.

B Taken from the same thin-section as photo A; shows the grain composition which varies from an aggregate of fine pellets to a mass of compressed lumps, with traces of fine skeletal material.

C Dolomitic limestone 40 feet from the top of the Nisku at Blackstone (Sec. 7, Twp. 42, Rge. 18, W5M). Scattered, very coarse, ovoid grains, partly calcite replaced, embedded in a microcrystalline calcite which contains numerous coarsley crystalline dolomite rhombs.

D Light grey limestone comprised of fine skeletal debris and abundant fine intraclasts or pellets in a matrix of sparry calcite. Sampled near the base of the Nisku at the same locality as photo A.

A similar black shale unit, 50 feet thick, is found at the base of the Nisku at Wapiabi Gap, Bighorn Range (Sec. 32, Twp. 40, Rge. 17, W5M, Fig. 2). The overlying argillaceous, silty dolomite contains thick black shale interbeds and rare fossils. All the above Nisku black shale has a petroliferous appearance and is considered to be a suitable source rock for oil and gas. The basal black shale is not present in the shale and limestone facies along the northern boundary of Jasper Park.

Age Problem of Nisku shale and Limestone facies

Brachiopods and corals from the Nisku shale and limestone facies of the Eaglesnest area (Sec. 17, Twp. 52, Rge. 4, W6M) are figured by Warren and Stelck (1956). This fossil suite, the *Tenticospirifer cyrtiniformis* zone, is considered to be upper Mount Hawk. A similar fauna is present within the Nisku at Winnifred Pass (Sec. 5, Twp. 54, Rge. 8, W6M), Glacier Pass (Sec. 14, Twp. 51, Rge. 6, W6M) and Boule Roche (Sec. 28, Twp. 49, Rge. 27, W5M). A similar brachiopod fauna from the Nisku shale facies of the Alberta Plains has been identified by D. J. McLaren (personal communication) as follows: *Tenticospirifer* cf. T. *cyrtiniformis* (Hall and Whitfield), *Schuchertella* cf. *S. prava* (Hall), *Leiorhynchus albertense* Warren, *Atrypa* cf. *A. devoniana,* and *Chonetes* sp. This Mount Hawk fauna is from the Imperial Cynthia 9-6 and 3-1 wells in Twp. 52, Rge. 11, W5M from the depths 8,882 to 8,884 feet and 8,655 to 8,700 feet, respectively. A paleontological correlation of the Nisku of the area north of the Athabasca River is thus established. Brachiopods were not found in the Nisku dolomite area, thus fossil corroboration of the correlation to the southern part of Figure 1 is not possible.

The Nisku shale and limestone facies of the southeast part of Jasper Park, particularly as developed at Medicine Lake, Beaver Ridge, (Sec. 8, Twp. 45, Rge. 26, W5M) contains a brachiopod fauna which may be younger than Mount Hawk. This is the *Nudirostra gibbosa walcotti* zone of McLaren (1954) and these beds are included by him within the Alexo formation. The basal black shale of this area, which is not fossiliferous, might be the only true Nisku time equivalent; the overlying green-grey shale and argillaceous limestone may have been deposited either during the pre-Alexo emergence as seen in the Nisku dolomite area to the south, or may represent an expanded deposit equivalent to the Calmar-like basal Alexo argillaceous sandstone of the area to the south. Direct brachiopod comparison to the Alexo type section is not possible because the type section is not fossiliferous.

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MIDDLE CAMBRIAN OF THE SOUTHERN ALBERTA PLAINS

H. van HEES [1]

ABSTRACT

The Cambrian of the Plains has been divided into Upper and Middle Cambrian. Correlations leading to this subdivision, which incorporates all conclusive paleontological evidence available to the author, are presented in three profiles, two of which extend into western Saskatchewan where the Middle Cambrian is widespread Middle Cambrian nomenclature typical of the Banff-Yoho Parks area is extended to the Plains. Maps and profiles emphasize two main lithologic types: carbonates, characteristic of the Rocky Mountains outcrops, in the west; and coarse, mainly rounded clastics, a diachronous eastern facies component that has its source on the Precambrian Shield.

A structure map, and an isopach map with superimposed elementary facies outlines in Plains and Mountains, further illustrate some aspects of the Middle Cambrian. Facies and thicknesses are closely related. Thicknesses increase from east to west. Four facies provinces governed by depth of deposition and distance from the clastic source area of the Pre-cambrian Shield are arranged in belts with roughly northwest-southeast trending boundaries. From east to west these are: (a) Coarse Basal Clastic Belt; (b) Glauconitic Silt-Shale Belt; (c) Submerging Shelf Carbonate Belt, culminating in a section of approximately 4,000 feet containing reefoid rocks in the Rocky Mountains; (d) Western Deeper Water Shale Belt, west of a line from Field, British Columbia to Blairmore, Alberta and farther southwest through Cranbrook, British Columbia where it attains a thickness of over 5,000 feet.

In the Plains a number of positive and negative depositional trends are observed. The negative trends are associated with carbonate deposition, the positive trends are devoid of carbonates.

Oil shows are summarized. Attention is given to the possibility that petroliferous reef-type carbonates, as found in the Eldon formation of the Mountains may extend into the Foothills and Plains.

GENERAL GEOLOGY

Middle and Upper Cambrian beds are present in the Plains area of southern Alberta. Lower Cambrian may be present under part of the Foothills, but has not been encountered by deep borings and will not be discussed further. Both the Middle and Upper Cambrian show facies changes and thinning eastward, due to onlap against the Precambrian Shield.

The Cambrian sequence is dominantly marine. However, at all times there has been a notable influx of clastics from a source area on the Precambrian shield. There is hardly a place where the diachronous basal beds, whatever their age may be, do not have a coarse clastic facies. One of the rare exceptions is the Princess area of southern Alberta. Structure contours, isopachs, and the absence of both carbonates and coarse rounded clastics, all indicate that the Princess area was an isolated topographic high, sufficiently elevated to prevent deposition of coarse sands carried from the Shield.

An example of absence of Middle Cambrian sediments due to non-deposition is presented in the southwest Saskatchewan well Imperial Battle Creek 4-31, (Lsd. 4, Sec. 31, Twp. 3, Rge. 26, W3M.), which appears to be located on a Precambrian anomaly that was not covered prior to Upper Cambrian time.

Although the Cambrian seas were transgressive, the encroachment of carbonate deposition was often overshadowed and halted by the influx of a mass of sand, derived from the Shield. The farther east, the more prominent becomes the sand facies. Specifically in northwestern Saskatchewan, this coarse sand facies entirely dominates both Upper and Middle Cambrian.

In the western half of southern Alberta, the Middle Cambrian has a carbonate facies that culminates in the Rocky Mountains in outcrops (thicknesses about 4,000 feet), containing a number of reef-type limestones and dolomites separated by prominent shale intervals which carry a diagnostic fauna.

Slightly farther west, roughly along a line from Field, British Columbia to Blairmore, Alberta, the carbonate facies changes abruptly into a thick shale sequence which suggests a change from a shelf environment to deeper water.

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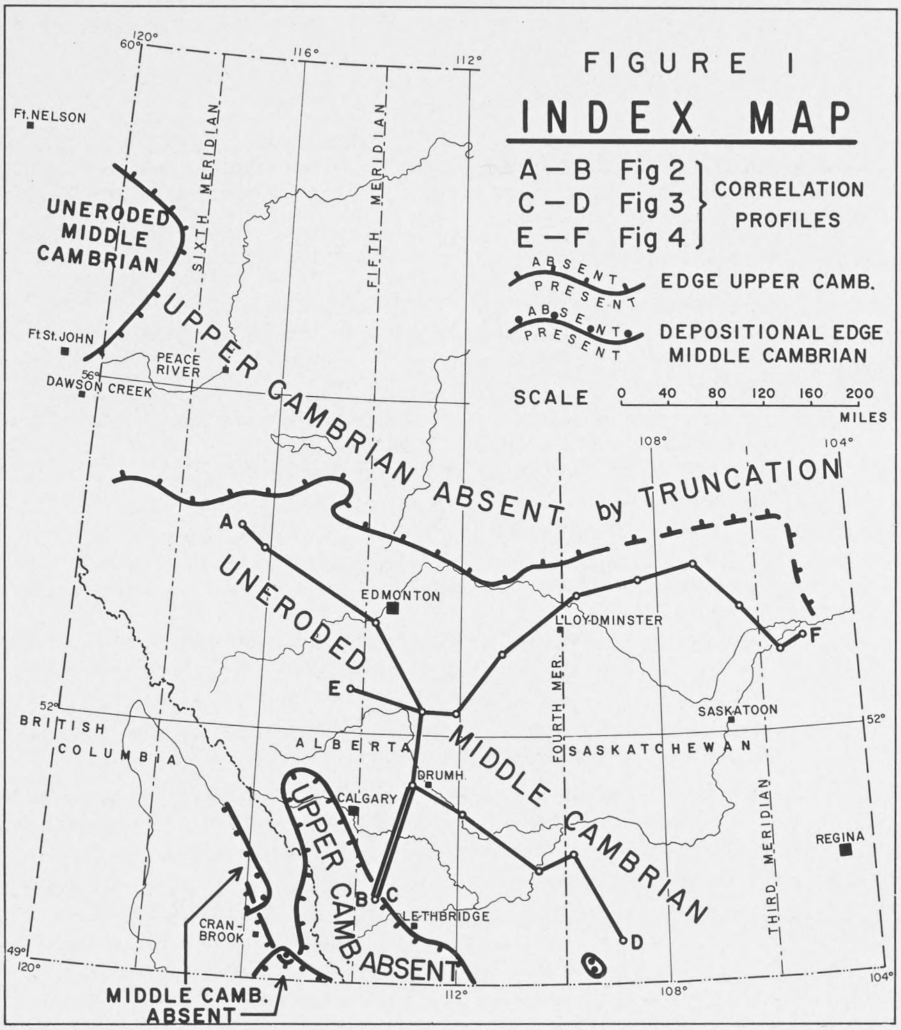


FIGURE 1

The index map (Fig. 1), shows the approximate distribution of uneroded Middle Cambrian. The outlines west of the Foothills belt are from North, (1953).

Considerable post-Cambrian erosion took place prior to the deposition of a Devonian cover, resulting in the removal of the Upper Cambrian and most of the Middle Cambrian from a large part of the map-area.

The maps in this paper are concerned with the areas that have a complete Middle Cambrian section. These areas are outlined in Figures 5 and 6 by the approximate limits of the uneroded Middle Cambrian. Outside these lines, Upper Cambrian has been removed entirely. North of the Peace River arch a crude outline is shown in Figures 1 and 5, of an area where uneroded Middle Cambrian is thought to be present.

In southeastern British Columbia the absence of Middle Cambrian is mainly the result of non-deposition. This is indicated by rapid thinning of all strata, whereas a cover of Upper Cambrian at Elko, British Columbia is further evidence that the thinness of underlying strata is not a result of post-Cambrian erosion.

The absence of Upper Cambrian in southwestern Alberta is believed to be the result of erosion. Truncation of the Middle Cambrian over the Plains portion of this area is slight and the configuration of isopachs and structure contours is little affected (Figs. 5 and 6).

Many of the above conclusions are dependent on determining the Upper-Middle Cambrian boundary in the Plains. Evidence pertaining to this basic problem is presented in the next two chapters.

Paleontological Evidence

Faunal evidence indicates that there is both, Middle and Upper Cambrian beneath the Plains of southern Alberta. Cambrian stratigraphy has been summarized and expanded recently by Raasch and Campau (1957), and Gussow (1957). The following information has been taken from these publications:

Calstan. Princess CPR No. 1 (Lsd. 13, Sec. 22, Twp. 20, Rge. 12, W4M.)

> *Dicellomus* sp. Identified by Edwin Kirk as Upper Cambrian.
> This occurrence is at the very top of the Cambrian in this well.

Commonwealth No. 1 (Lsd. 8, Sec. 9, Twp. 3, Rge. 15, W4M.)

> *Obolus mcconnellii* at 5,220 feet. Identified by P. S. Warren.
> This is a Middle Cambrian form found in the Stephen and Eldon formations of the Castle (Eisenhower) Mountain section.
> Author's note: The top of the Cambrian is at 5,205 feet. It follows that Upper Cambrian is almost certainly absent in this well.

Imperial Provost No. 2 (Lsd. 1, Sec. 33, Twp. 37, Rge. 3, W4M.)

> *Dicellomus* cf. *D. occidentalis* Bell
> *Dicellomus* cf. *D. amblia* Bell
> *Linnarsonella* sp.
> Identified by C. W. Bell as lower Upper Cambrian.

Calstan. Parkland No. 4-12 (Lsd. 4, Sec. 12, Twp. 15, Rge. 27, W4M.)

> Raasch and Campau (1957) give a detailed faunal subdivision of this entirely Middle Cambrian section into the Eldon, Stephen, and Cathedral formations of the Banff-Yoho Parks area.

Fina-Stanolind-Hudson's Bay Windfall 12-36 (Lsd. 12, Sec. 36, Twp. 59, Rge. 15, W5M).

> *Glossopleura.* Reported by Raasch and Campau (1957) from a cored interval 10,923 to 10,924 feet. A lower Stephen form.

Credit for the first published attempt to establish a reliable Upper-Middle Cambrian boundary in the subsurface goes to deMille and Crickmay, (deMille 1958). deMille presents a cross-section that includes the Windfall 12-36 well, where the Upper-Middle Cambrian boundary is shown. This boundary in the Windfall well, and the Middle Cambrian formations as identified by Raasch and Campau (1957) in the Parkland well, are the controlling factors in the subdivision of the Cambrian presented in this paper. The following additional information has been collected during this study.

Crickmay (personal communication) states that *Linnarsonella* and *Dicellomus,* are present in cored intervals in the Provost No. 2 well at 5,648 feet and 6,070 feet respectively. He adds that *Dicellomus,* although most abundant in the Upper Cambrian, may also be found in the uppermost Middle Cambrian.

Raasch (personal communication) reports *Tonkinella,* an upper Stephen trilobite from 9,300 feet in Texaco Wizard Lake B-3 (Lsd. 15, Sec. 21, Twp. 48, Rge. 27, W4M.).

Canadian Stratigraphic Service log No. 833 of Calstan. East Gilby 4-5 (Lsd. 4, Sec. 5, Twp. 41, Rge. 2 W5M.) has *Dicellomus* and *Crephicephalus* in a cored interval of 10,480 to 10,500 feet. These forms were identified by G. O. Raasch who comments, "This indicates a correlation with the Sullivan formation of Upper Cambrian age."

Porter and Fuller (1958) report the Upper Cambrian form *Dicellomus politus* Hall from the depth interval 2,707 to 2,726 feet in the Imperial Blue Bell well (Lsd. 2, Sec. 13, Twp. 60, Rge. 20, W3M.).

Correlations and Facies Changes

Three profiles are employed to demonstrate Cambrian correlations throughout the Plains of southern Alberta. All three profiles have as datum the Upper-Middle Cambrian boundary. Lithology has been treated diagrammatically by using only three rock classifications: (a) carbonates, (b) coarse basal clastics, and (c) fine clastics, such as shale, silt, and fine sand.

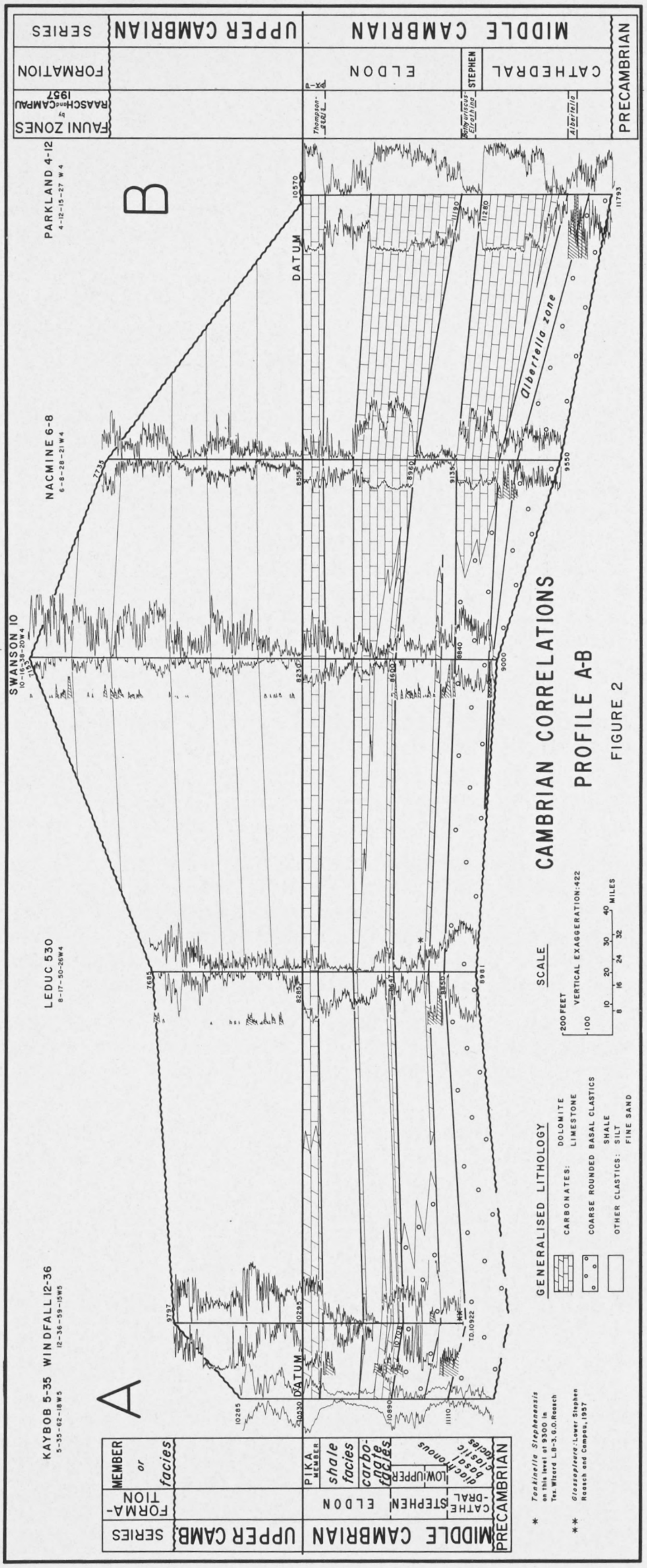

CAMBRIAN CORRELATIONS
PROFILE A-B
FIGURE 2
A
B
KAYBOB 5-35
WINDFALL 12-36
LEDUC 530
SWANSON 10
NACMINE 6-8
PARKLAND 4-12
DATUM
Albertella zone
SCALE
VERTICAL EXAGGERATION: 422
MILES
GENERALISED LITHOLOGY
CARBONATES: DOLOMITE
LIMESTONE
COARSE ROUNDED BASAL CLASTICS
OTHER CLASTICS: SHALE
SILT
FINE SAND
SERIES
FORMATION
FAUNI ZONES
MEMBER or facies
UPPER CAMBRIAN
MIDDLE CAMBRIAN
PRECAMBRIAN
ELDON
STEPHEN
CATHEDRAL

FIGURE 2

PROFILE A-B, PARKLAND 4-12 TO KAYBOB 5-35

This profile (Fig. 2) traces the Cambrian from Calstan. Parkland 4-12 (Lsd. 4, Sec. 12, Twp. 15, Rge. 27, W4M.) north, and north-westward to Calstan. Gulf Kaybob 5-35 (Lsd. 5, Sec. 35, Twp. 62, Rge. 18, W5M.). See Figure 1. Most of the diagnostic faunal evidence is incorporated in this profile, which gives a breakdown of the Middle Cambrian into formations.

Marked facies changes are shown on this profile. In the depositionally deeper south part, the Middle Cambrian is mainly represented by massive carbonates interbedded with green shales. Here, only the basal part of the Cathedral below the *Albertella* zone has a basal clastic sand facies. Northward, this diachronous basal clastic facies moves up in the section and the Cathedral limestone pinches out against it. Correspondingly the main Eldon limestone becomes thinner northward and eventually is intertongued with shale and silt. In profile A-B this change occurs gradually because the northward trace of the section is at a slight angle from the trend of maximum carbonate development, of which the Parkland 4-12 well is the best Plains example. Profile C-D, (Fig. 3) and E-F, (Fig. 4) which will be discussed later, show a similar but more rapid change in an eastward direction.

The thinnest development of the Stephen formation is at Parkland 4-12 where it is only 90 feet thick. It thickens in all directions from this locality and is 222 feet thick at Windfall. The Upper Stephen *Tonkinella* fauna, that is projected from Texaco Wizard Lake B-3, (Lsd. 15, Sec. 21, Twp. 48, Rge. 27, W4M.) to Imperial Leduc 530 on profile A-B, and the *Glossopleura* fauna of Windfall 12-36, enables a break-down into Upper and Lower Stephen at the northern end of profile A-B.

The total thickness of Stephen plus Eldon is fairly constant; 710 feet at Parkland and 650 feet at Windfall 12-36. The base of the Eldon is represented by a dolomite where the main carbonate is intertongued with shale. The Pika member of the Eldon remains fairly constant in thickness but changes to dolomite between Leduc 530 and Windfall 12-36. It thins and disappears eastward.

Formation names established at Parkland 4-12 have been carried across this profile. The *Albertella* zone of the Cathedral formation is tentatively carried some distance north of Gulf Swanson No. 10 on the basis of its inferred presence as a thin highly radioactive response on the Gamma Ray log near the bottom of the basal sand in this well. The Cathedral age of this sand in the Kaybob-Windfall area is apparent because it is overlain by Lower Stephen shale with *Glossopleura.*

The Upper Stephen of Kaybob and Windfall consists of clastics, whereas the Lower Stephen still retains its shaly facies. To the northwest and more particularly to the northeast, coarser clastics are also present in this lower interval. The abundance of clastics indicates close proximity to the Shield in this area. The diachronous basal Middle Cambrian sand facies extends to the top of the Stephen in the same manner as the basal sand facies extends stratigraphically higher in the Cathedral formation between the Parkland and Swanson wells. Ninety miles northeast of Windfall coarse basal clastics constitute 50 percent of the Middle Cambrian.

PROFILE C-D, PARKLAND 4-12 TO DORRELL 32-9

Profile C-D (Fig. 3) ties in with profile A-B at Parkland 4-12 and Nacmine 6-8, then extends eastward to Mobil Dorrell 32-9 (Lsd. 9, Sec. 32, Twp. 6, Rge. 22, W3M.). It follows a negative structural and depositional trend in the southern part of the map-area. It is comparable to profile A-B but facies changes are more prominent. The top of the Cathedral formation can be carried with certainty past Mobil Hutton 11-18. Farther east, in Richfield Rapid Narrows 11-20, the Cathedral limestone is replaced by the diachronous basal sand. The *Albertella* shale becomes more sandy eastward but equivalent beds may still be recognized in the Rapid Narrows well, by high radioactivity response on the Gamma Ray log.

The overlying Stephen formation retains its shale facies until it reaches the eastern end of the profile where, in Mobil Dorrell 32-9, a tongue of diachronous basal clastics indicates the end of uninterrupted shale deposition. The carbonate facies of the Eldon formation continues as far east as North Richmond 31-1 but becomes increasingly shaly east of Rapid Narrows 11-20. Only a thin dolomite sequence is present in the lower part at Dorrell 32-9. This change is analogous to that at the northern end of Profile A-B.

The Upper-Middle Cambrian boundary can be followed eastward to the Mobil North Richmond well, where only a very thin limestone represents the Pika member of the Eldon. The boundary has been traced farther on mechanical log picks which appear to have good support from traceable markers in the Upper Cambrian.

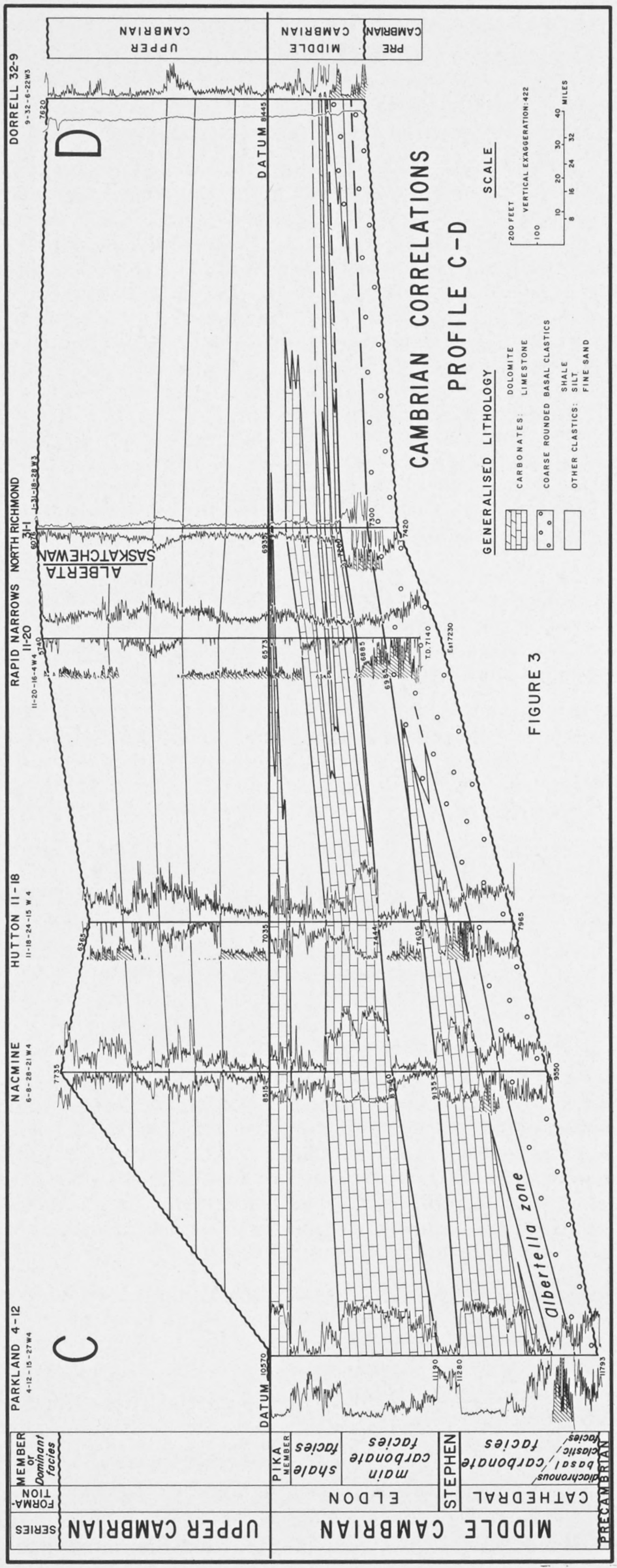

CAMBRIAN CORRELATIONS
PROFILE C-D
C
D
PARKLAND 4-12
4-12-15-27W4
NACMINE
6-8-28-21W4
HUTTON 11-18
11-18-24-15 W 4
RAPID NARROWS
11-20
11-20-16-4W4
NORTH RICHMOND
31-1
1-31-18-28W3
DORRELL 32-9
9-32-6-22W3
ALBERTA
SASKATCHEWAN
DATUM
Albertella zone
SERIES
FORMATION
MEMBER or Dominant facies
UPPER CAMBRIAN
MIDDLE CAMBRIAN
PRECAMBRIAN
ELDON
STEPHEN
CATHEDRAL
PIKA MEMBER
shale facies
main carbonate facies
carbonate facies
diachronous basal clastic facies
UPPER CAMBRIAN
MIDDLE CAMBRIAN
PRE CAMBRIAN
GENERALISED LITHOLOGY
CARBONATES: DOLOMITE
LIMESTONE
COARSE ROUNDED BASAL CLASTICS
OTHER CLASTICS: SHALE
SILT
FINE SAND
SCALE
200 FEET
100
VERTICAL EXAGGERATION 422
MILES
FIGURE 3

FIGURE 3

The basal sand facies along this profile ranges in age from pre-*Albertella* Cathedral in the west to uppermost Stephen in the east.

PROFILE E-F, EAST GILBEY 4-5, TO SORBY 13

Profile E-F (Fig. 4) extends from East Gilbey 4-5 (Lsd. 4, Sec. 5, Twp. 41, Rge. 2, W5M.) northeastward to B.A. Sorby No. 13 (Lsd. 13, Sec. 16, Twp. 47, Rge. 22, W2M.) in Saskatchewan (Fig. 1), and follows a line of maximum facies change from a carbonate in the southwest, to an entirely basal clastic section in the northeast that reaches far up into the Upper Cambrian.

It is not possible to trace Middle Cambrian formation equivalents into the eastern part of the profile because of the absence of conclusive faunal evidence. East of Gulf Swanson No. 10 the carbonates change into a facies of shales, glauconitic silts and fine sands with numerous indications of fossil debris. Available faunal evidence differentiates only Upper and Middle Cambrian. In the eastern part of the profile mechanical and litholigic markers are sufficiently reliable to be used as an aid in correlating. The Upper-Middle Cambrian boundary can be traced by these markers in such a manner that the Upper and Middle Cambrian faunas are respectively above and below. Only in the Provost area is there some possibility of minor discrepancy. In Imperial Provost No. 2 (Lsd. 1, Sec. 3, Twp. 37, Rge. 3, W4M.) the Upper-Middle Cambrian boundary had to be placed at 6,000 feet. This is above a lower Upper Cambrian *Dicellomus* fauna so qualified by C. W. Bell, from a depth of 6,070 feet. The high placement at 6,000 feet is necessary to conform with our boundary elsewhere. This finds support from Crickmay's statement that some forms of *Dicellomus* may occur in the upper part of the Middle Cambrian.

The author (1958), gave a Cambrian subdivision in northwestern Saskatchewan which assisted in establishing the amount of truncation of the Cambrian north of the Meadow Lake escarpment. At that time the presence of Middle Cambrian was not recognized. The "Upper Glauconitic" and "Upper Coarse" of the Meadow Lake area remain in the Upper Cambrian. The "Lower Glauconitic" now straddles the Upper-Middle Cambrian boundary.

BASIN FRAMEWORK AND RELATED FACIES TRENDS

By determining the position of the Upper-Middle Cambrian boundary in the Plains, it is possible to draw certain conclusions pertaining to the depositional and tectonic history of the Upper and Middle Cambrian.

The erosional limits of the Upper Cambrian are shown in Figure 1. Within these limits the uneroded Middle Cambrian is preserved. Middle Cambrian isopachs and structure contours are shown in Figures 5 and 6. In addition Figure 5 illustrates elementary facies trends.

BASINAL TRENDS

NORTHWEST

Northwest striking isopachs (Fig. 5) indicate that the thickness of the Middle Cambrian of the Plains increases westward. This basinal trend continues along a line from Calgary southeast to Lethbridge and farther into Montana, where the isopachs reflect a south-eastward shallowing embayment. It is bounded on the west by a depositional edge on the Lewis overthrust which originates an unknown distance to the west. Middle Cambrian gradually thickens from Edmonton southwest to the Foothills belt. Thicknesses appear to culminate farther to the west in the Rocky Mountains where thick carbonate sediments have accumulated to 4,500 feet in Mt. Robson, 4,000 feet in the Banff-Yoho Parks area and 3,000 feet in Mt. Assiniboine (North and Henderson, 1954).

This basin trend referred to above, is characterized by the carbonate facies of the Middle Cambrian.

NORTHEAST

A second major basinal trend can be inferred to extend from North's (1953) Idaho Strait in the Cranbrook area of British Columbia (Fig. 5), north-eastward through Drumheller, and Lloydminster. A southern arm branches off east of Princess.

In the Plains this trend also has a facies characterized by carbonates. The Middle Cambrian of the Cranbrook area, however, is mainly developed in a shale facies similar to the Chancellor formation (North and Henderson, 1954) west of the Field-Blairmore line.

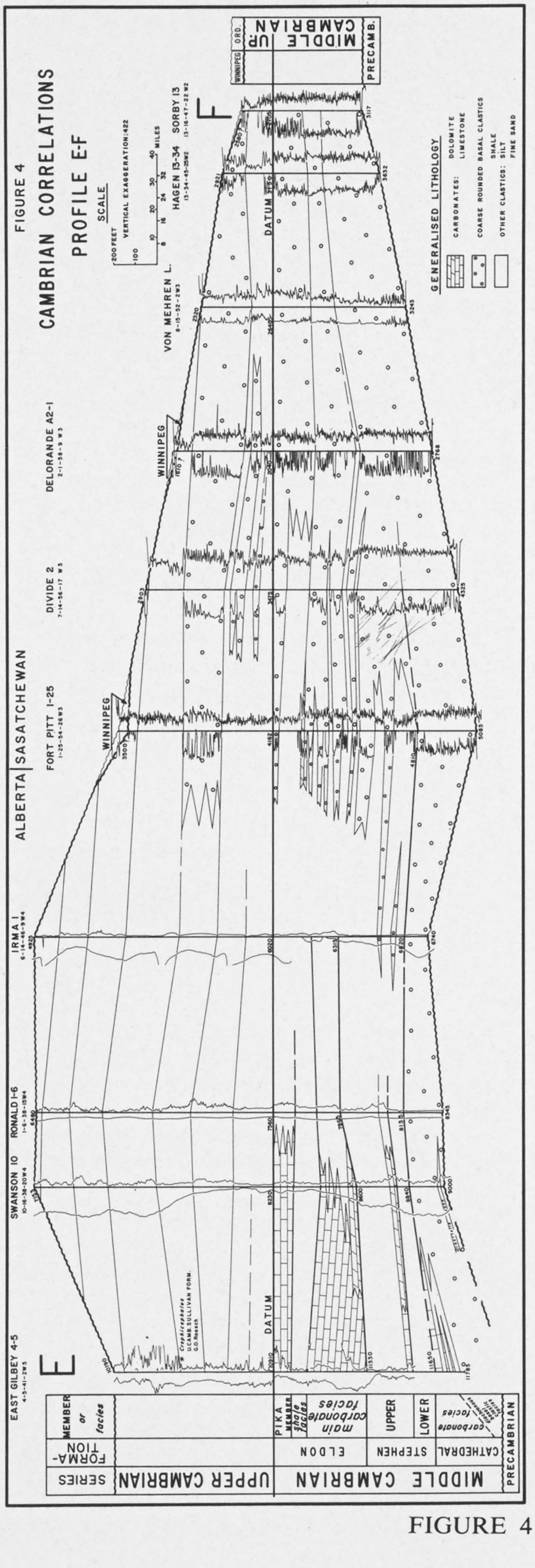


FIGURE 4
CAMBRIAN CORRELATIONS
PROFILE E-F
SCALE
200 FEET
VERTICAL EXAGGERATION: 422
MILES
EAST GILBEY 4-5
SWANSON 10
RONALD 1-6
IRMA 1
ALBERTA
SASATCHEWAN
FORT PITT 1-25
DIVIDE 2
DELORANDE A2-1
VON MEHREN L.
HAGEN 13-34
SORBY 13
WINNIPEG
DATUM
E
F
SERIES
FORMA-TION
MEMBER or facies
UPPER CAMBRIAN
MIDDLE CAMBRIAN
PRECAMBRIAN
ELDON
STEPHEN
CATHEDRAL
PIKA MEMBER
shale facies
main carbonate facies
UPPER
LOWER
carbonate facies
GENERALISED LITHOLOGY
CARBONATES: DOLOMITE LIMESTONE
COARSE ROUNDED BASAL CLASTICS
OTHER CLASTICS: SHALE SILT FINE SAND
WINNIPEG
ORD.
UP. CAMBRIAN
MIDDLE CAMBRIAN
PRECAMB.

FIGURE 4

POSITIVE TRENDS

PRINCESS AREA

The isopach map (Fig. 5) shows a thin development of Middle Cambrian in the southern Alberta wells Calstan. Princess CPR No. 1 (Lsd. 13, Sec. 22, Twp. 20, Rge. 12, W4M.) and Imperial Grassy Lake No. 3 (Lsd. 2, Sec. 35, Twp. 10, Rge. 13, W4M). Isopachs suggest that this high extends into Montana. It partially reflects the northern end of the Sweetgrass arch which, however, is now larger and extends over the southern part of the northwest basinal trend, (Fig 6). The Princess high is cut off on the north by the Cranbrook-Lloydminster basinal trend, which appears to be constricted by it.

Carbonates are absent on all Middle Cambrian positive trends including the Princess high. The sediments on the Princess high consist of glauconitic silts, green shales, and fine sands.

EDMONTON-DRUMHELLER-WAINWRIGHT TRIANGLE

A thin Middle Cambrian is present to the east of Edmonton. It is bounded on the west by the northwest basinal trend and on the south and southeast by the Drumheller-Lloydminster embayment. Its south plunging axis may line up with the Princess high. The facies is similar to that of the Princess area. It is intermediate between the western carbonates and the eastern coarse basal clastics.

PEACE RIVER ARCH

In the northwest, close to the erosional edge, the strike of the isopachs changes from northwest to west. This area is proximal to the south side of the Peace River arch. Later erosion has removed practically all Cambrian sediments from the arch and obscured the history of the Middle Cambrian over this area.

The 50 percent sand isolith (Fig. 5) can be extended from its termination at the erosional edge southeast of the arch to the northwest side as if it once extended straight across.

The eastern margin of Eldon carbonates maintains its northwest direction south of the arch to the point where it also is obscured by erosion. In this area, however, only the Pika member is developed as a carbonate since the Eldon main carbonate is already shaled out. Only a feather edge of the Eldon main carbonate is found in Windfall 12-36, situated 90 miles to the west. This shows that the main Eldon carbonate development swings westward on the south side of the arch. In the Fort St. John region, north of the arch, carbonates extend eastward.

The facies interpretation suggests that the Peace River arch existed in Middle Cambrian time and that it was too high for carbonate deposition but not high enough to prevent the deposition of clastics of which the coarse fraction suggests proximity to the Shield.

SOUTHERN ROCKY MOUNTAINS

In the Clarke Range, Beltian rocks of the Lewis overthrust are overlain by thinned Middle Cambrian sediments. North (1953) reports 60 feet of Middle Cambrian at Elko, British Columbia and 250 feet on Windsor Mountain, containing faunas that range from basal Cathedral to Upper Stephen in age.

SUMMARY

Middle Cambrian thicknesses increase from east to west. The amount of clastics follows a reversed pattern and increases eastward, pointing to an eastern source. In embayments and shallow seaways the deposition of carbonates was apparently governed by a certain critical depth requirement. Farther west, away from the influx of clastics, the carbonates show indications of agitated waters, in the appearance of oolites. This trend culminates in the Rocky Mountains section where North and Henderson (1954) describe the Eldon as a reef-type petroliferous rock. This suggests that even though thicknesses of Middle Cambrian in the Banff-Yoho Parks area are over 4,000 feet, the carbonates are high energy shallow water deposits of a submerging shelf.

Middle Cambrian carbonates change abruptly into the thick shale section of the Chancellor and equivalent formations roughly west of a line from Field, British Columbia to a point approximately 15 miles north of Blairmore. This termination of shelf carbonate environment is suggestive of a hinge-line between shelf environment and deeper water, where subsidence was too rapid

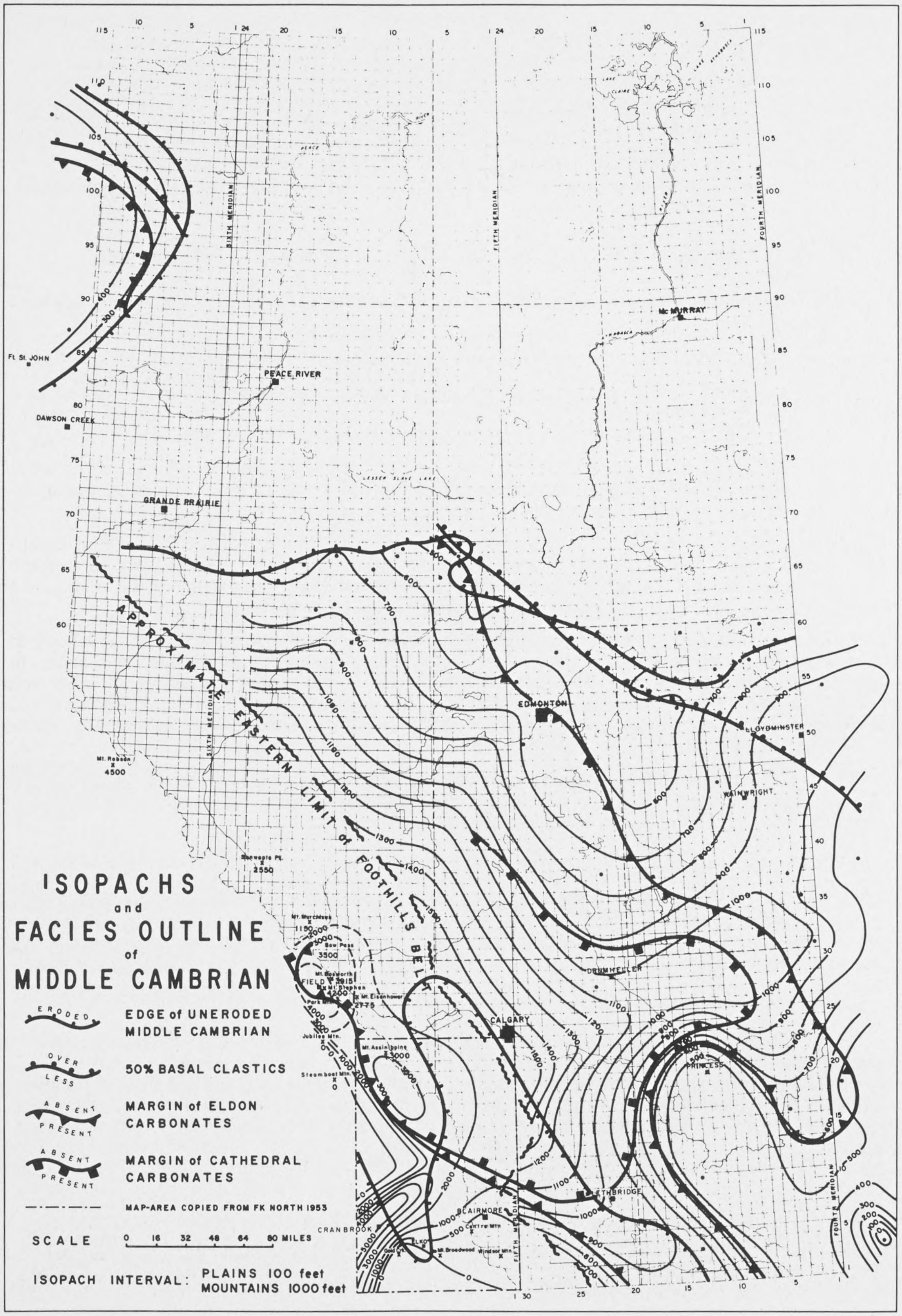

ISOPACHS
and
FACIES OUTLINE
of
MIDDLE CAMBRIAN
EDGE of UNERODED MIDDLE CAMBRIAN
50% BASAL CLASTICS
MARGIN of ELDON CARBONATES
MARGIN of CATHEDRAL CARBONATES
MAP-AREA COPIED FROM FK NORTH 1953
SCALE 0 16 32 48 64 80 MILES
ISOPACH INTERVAL: PLAINS 100 feet
MOUNTAINS 1000 feet
APPROXIMATE EASTERN LIMIT of FOOTHILLS BELT
SIXTH MERIDIAN
FIFTH MERIDIAN
FOURTH MERIDIAN
Ft. St. JOHN
DAWSON CREEK
PEACE RIVER
GRANDE PRAIRIE
McMURRAY
EDMONTON
LLOYDMINSTER
WAINWRIGHT
DRUMHELLER
CALGARY
PRINCESS
LETHBRIDGE
BLAIRMORE
CRANBROOK
ELKO
FIELD
Mt. Robson 4500
Mt. Murchison
Bow Pass
Mt. Assiniboine
Jubilee Mtn.
Steamboat Mtn.
LESSER SLAVE LAKE

FIGURE 5

for reef-type deposition. This western shale trough connects with the Idaho strait and is generally parallel to the Rocky Mountain Trench. It is devoid of coarse clastics and was probably filled with detritus from the abraded Beltian rocks of the southern Rockies supplemented with the finest eastern clastics that were kept in suspension while swept over the current-agitated shelf area.

On the basis of the facies outlines superimposed on the isopach map (Fig. 5), the Middle Cambrian can be divided into four facies provinces. From east to west these are:

(1) Coarse Basal Clastic Belt, northeast of the 50 percent isolith.

(2) Glauconitic Silt-Shale Belt, between the 50 percent isolith and eastern margin of carbonates. This belt includes the Princess area, Edmonton-Drumheller-Wainwright triangle, and possibly the west part of the Peace River arch.

(3) Submerging Shelf Carbonate Belt, outlined by the eastern and western margins of carbonate deposition.

(4) Western Deeper Water Shale Belt, in the Idaho Strait and west of the Field-Blairmore hinge-line.

Petroleum and Natural Gas

To date there has been no oil or gas production from the Cambrian. However, because of a number of hydrocarbon shows, one commercial occurrence of helium, and the low incidence of penetration by wells, the prospectiveness of this sequence should not be disregarded.

In the Elk Point area of eastern Alberta there are at least two wells in which oil stained sands have been reported. These sands are present near the Upper-Middle Cambrian boundary and are probably lenticular.

In the Windfall-Kaybob area in the northwest, oil stains are reported on Canadian Stratigraphic logs No. 879 of Windfall 12-36 and on log No. 860 of Kaybob 5-35 in Upper and Middle Cambrian fine sands and dolomites, far below the unconformity.

North and Henderson (1954) describe the Eldon of the Mountains as follows. "The Eldon is a great dolomite formation of which large parts bear an unmistakably reefoid aspect, pale pink to buff or white in color, unbedded, almost structureless, without fossils except for some algae, in many parts coarse, vuggy, hematitic, and petroliferous". The westernmost Plains wells with well developed Eldon carbonates are Parkland 4-12 (Lsd. 4, Sec. 12, Twp. 15, Rge. 27, W4M.) and East Gilbey 4-5 (Lsd. 4, Sec. 5, Twp. 41, Rge. 2, W5M.). The Eldon consists of slightly dolomitic limestone in both wells. The limestone is mainly tan coloured, often dense and argillaceous and is not reef limestone. It has, however, streaks and bands of algae and some oolites, indicating periods of agitated water. This lithology may indicate a proximity to better reefoid developments, possibly to the west. The Foothills belt holds possibilities of reef-type developments like those in the Banff-Yoho Parks area.

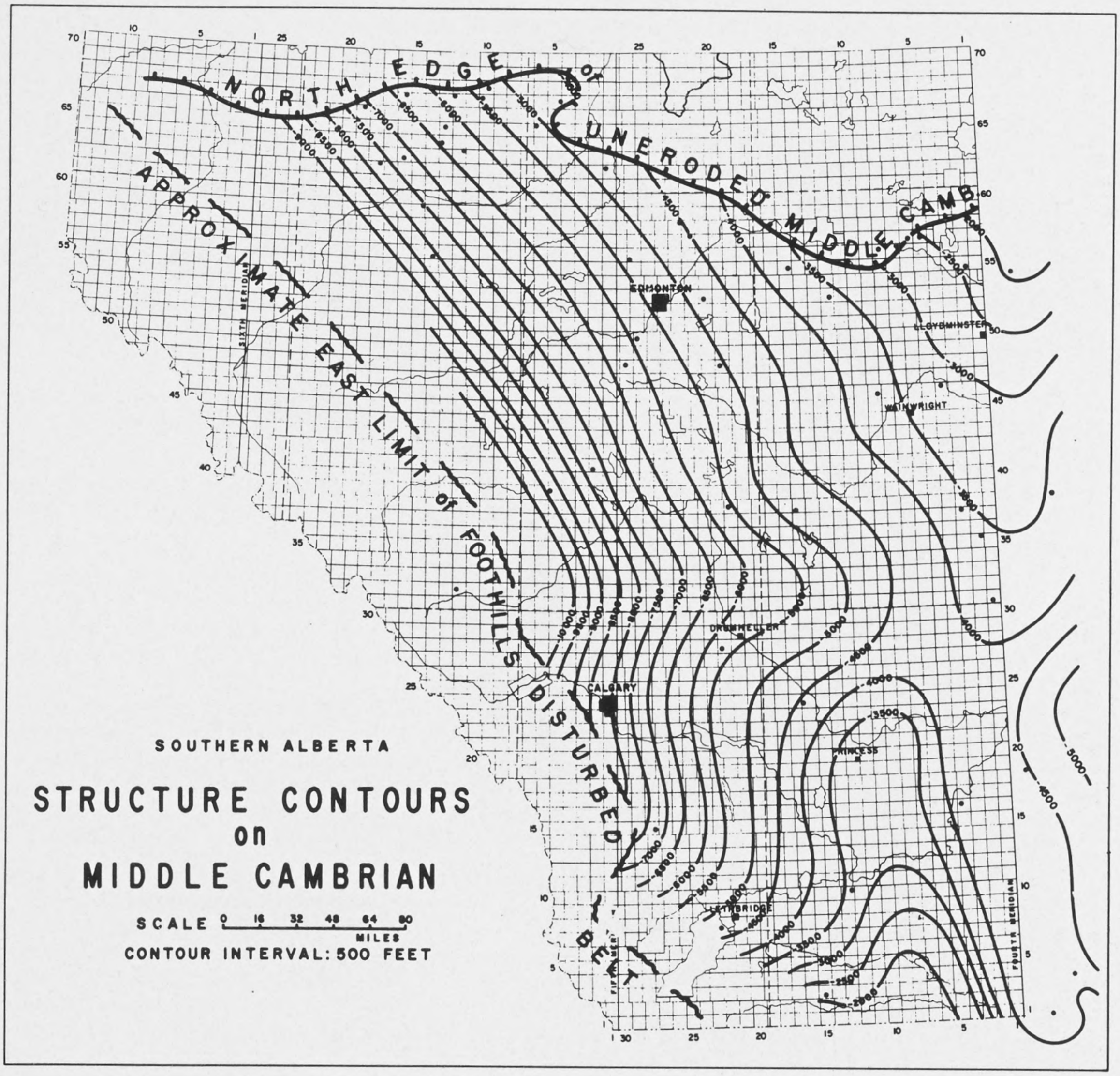
A discovery of helium, in commercial quantities, was reported from the Saskatchewan well B. A. Wilhelm 1-9 (Lsd. 1, Sec. 9, Twp. 17, Rge. 14, W3M.). According to the correlations presented in this paper, the gas occurs in the basal 200 feet of a silicified Upper Cambrian sand that rests directly on a Precambrian high, or monadnock, around which the Middle Cambrian pinches out. The Imperial Battle Creek 4-31 anomaly (Lsd. 4, Sec. 31, Twp. 31, Rge. 26, W3M.) mentioned previously in this paper and illustrated in Figures 1, 5 and 6, is one of a number of similar anomalies in western Saskatchewan. The well has inert gas, mostly nitrogen, in various zones, but the basal silicified Cambrian sand was not tested.

Helium is a product of radioactive disintegration and might be released from radioactive minerals in the Precambrian, either proximal to the reservoir or in the anomaly itself. The simultaneous occurrence of nitrogen, most likely a residual magmatic gas, and the anomalous silicification of the sediments immediately overlying the Precambrian highs of Wilhelm and Battle Creek does suggest that the structure itself is the source of the gas.

The Princess high in southern Alberta may be a similar situation.

Conclusion

This outline may serve as a basis from which more detailed studies can be undertaken. For instance, the carbonates of the Cathedral formation, Eldon main carbonate and, the Pika carbonate can be mapped separately and with much more facies detail. This may consolidate exploration trends that have been mentioned as possibilities.


NORTH EDGE of UNERODED MIDDLE CAMB
APPROXIMATE EAST LIMIT of FOOTHILLS DISTURBED BELT
EDMONTON
LLOYDMINSTER
WAINWRIGHT
DRUMHELLER
CALGARY
PRINCESS
LETHBRIDGE
SIXTH MERIDIAN
FIFTH MERIDIAN
FOURTH MERIDIAN
SOUTHERN ALBERTA
STRUCTURE CONTOURS
on
MIDDLE CAMBRIAN
SCALE 0 16 32 48 64 80
MILES
CONTOUR INTERVAL: 500 FEET

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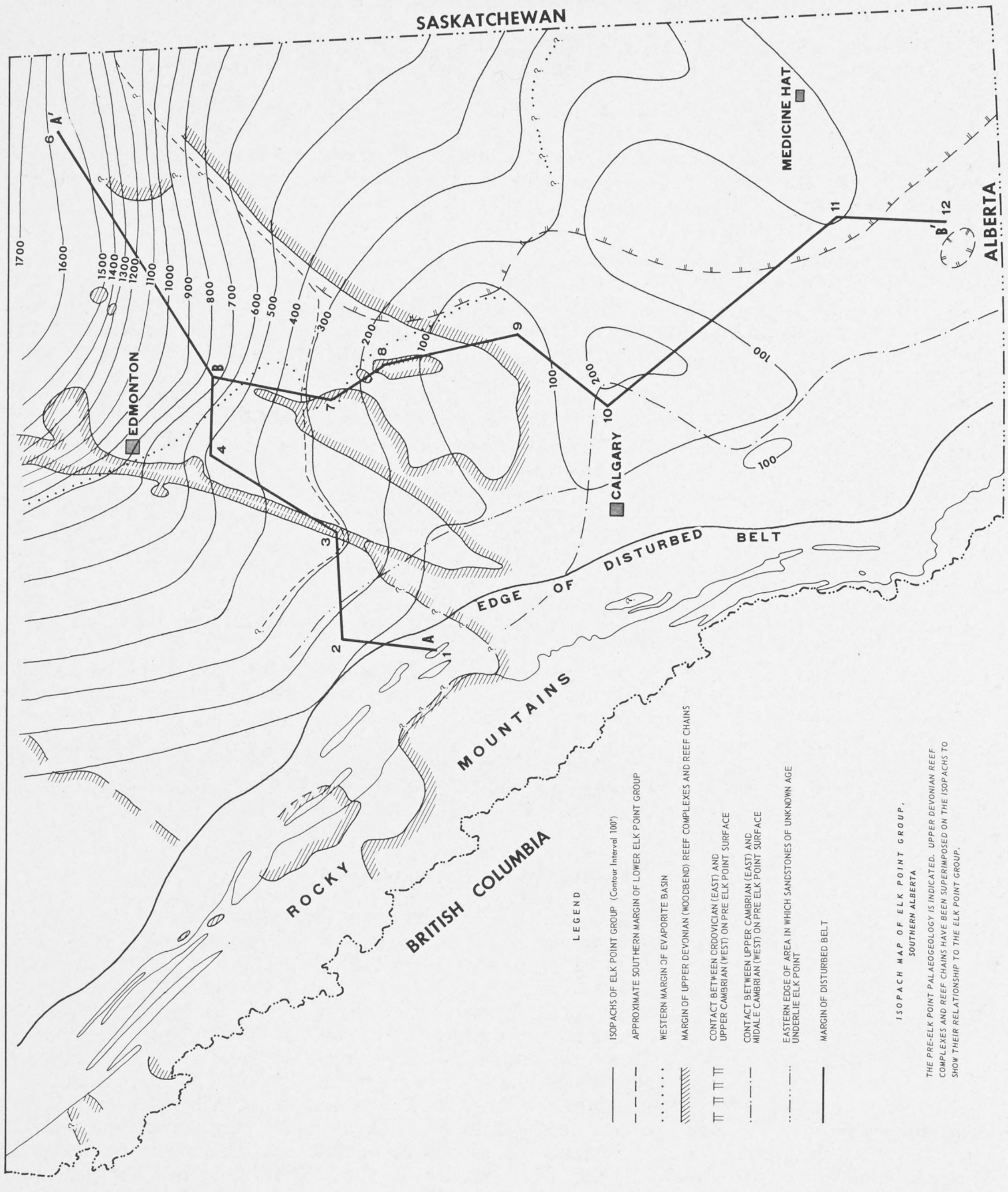
SASKATCHEWAN
ALBERTA
BRITISH COLUMBIA
ROCKY MOUNTAINS
EDGE OF DISTURBED BELT
EDMONTON
CALGARY
MEDICINE HAT
A
A'
B
B'
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
LEGEND
ISOPACHS OF ELK POINT GROUP (Contour Interval 100')
APPROXIMATE SOUTHERN MARGIN OF LOWER ELK POINT GROUP
WESTERN MARGIN OF EVAPORITE BASIN
MARGIN OF UPPER DEVONIAN (WOODBEND) REEF COMPLEXES AND REEF CHAINS
CONTACT BETWEEN ORDOVICIAN (EAST) AND UPPER CAMBRIAN (WEST) ON PRE ELK POINT SURFACE
CONTACT BETWEEN UPPER CAMBRIAN (EAST) AND MIDDLE CAMBRIAN (WEST) ON PRE ELK POINT SURFACE
EASTERN EDGE OF AREA IN WHICH SANDSTONES OF UNKNOWN AGE UNDERLIE ELK POINT
MARGIN OF DISTURBED BELT
ISOPACH MAP OF ELK POINT GROUP,
SOUTHERN ALBERTA
THE PRE-ELK POINT PALAEOGEOLOGY IS INDICATED. UPPER DEVONIAN REEF COMPLEXES AND REEF CHAINS HAVE BEEN SUPERIMPOSED ON THE ISOPACHS TO SHOW THEIR RELATIONSHIP TO THE ELK POINT GROUP.

FIGURE 1

ELK POINT GROUP, SOUTHERN AND CENTRAL ALBERTA [1]

H. R. BELYEA [2]

Introduction

The following is a summary of a paper on the Elk Point group in Alberta south of Township 60. The detailed paper will be published by the Geological Survey of Canada.

The Elk Point was introduced as a formation by J. R. McGehee in 1949. It was described from the cores and samples of a number of wells drilled in the Elk Point area and was extended from that area to include homotaxial units in southern Alberta and Saskatchewan. It was given group status by Belyea in 1952 because it includes a number of separately mappable units which are not necessarily co-extensive.

Stratigraphy

The sediments of the Elk Point group were deposited in a northwesterly trending basin extending from southern Manitoba to the Northwest Territories. A belt in the central part of the basin contains from one to three large salt beds and was designated the 'evaporite basin' by Crickmay (1954). Its western limit in Alberta is shown in Figure 1.

Crickmay in 1954 designated nine informal members in the Elk Point area, where the Elk Point group is near its maximum development (Fig 2). From the top down this sequence is comprised as follows, — Member 1: green and red shales, dolomite, anhydrite; Member 2: the 'first salt;' Member 3: fossiliferous limestone and dolomite, containing an upper zone with reef-type lithology and a lower zone, consisting of argillaceous limestone (correlated by Crickmay with the Winnipegosis); Member 4: orange-red shale, siltstone and dolomite (correlated with theAshern by van Hees); Member 5: the 'second salt;' Member 6: white anhydrite and limestone with osctracodes; Member 7: grey and red shale; Member 8: the 'third salt;' Member 9: orange-red shales, siltstone, anhydrite with coarse sand grains and glauconite towards the base. van Hees (1956) placed members 1 to 4 in the Upper Elk Point and members 5 to 9 in the Lower Elk Point.

The Lower Elk Point seems to be present only in the northeastern part of the map-area, its approximate limits being indicated on Figure 1. No positive evidence as to its age has been obtained. The Upper Elk Point, of known Middle Devonian age, is more extensive than the Lower Elk Point (Figs. 2 and 3). The individual members are not recognizable beyond the limits of the 'evaporite basin,' having changed facies southward and westward into anhydritic claystones, shaly limestones and dolomite, shale and interbedded siltstones and sandstones, the latter increasing in abundance westwards; red and green colors are common.

Pre-Elk Point Paleogeology

The Elk Point group rests on truncated Cambrian and Ordovician sediments. The subcrop of the Ordovician on the pre-Devonian surface is present in the southeast part of Alberta (Fig. 1), where it is overlain by three members of the Elk Point group. At California Standard Parkland 4-12 (Lsd. 4, Sec. 12, Twp. 15, Rge. 27, W4M) in southwestern Alberta a thin Elk Point sequence rests on limestones, shown by Raasch and Campau (1957) to be Middle Cambrian. Between these two areas and northward over central Alberta, the Elk Point rests on light grey, calcareous, glauconitic siltstones with interbedded maroon and green shales of the Upper Cambrian. In western Alberta the Elk Point overlies fine to coarse-grained, poorly sorted quartzose sandstones which may in part be correlative with sandy beds included in the Elk Point elsewhere, or sandstones of more than one age may occur in the area. Warren (personal communication) has found lower Ordovician faunal elements in sandstones below the Devonian in Altoba and Canyon Clearwater No. 1 (Lsd. 5, Sec. 31, Twp. 34, Rge. 9, W5M). In the Windfall area of central Alberta, sandstones present below the Devonian carbonates may also be Devonian in age.

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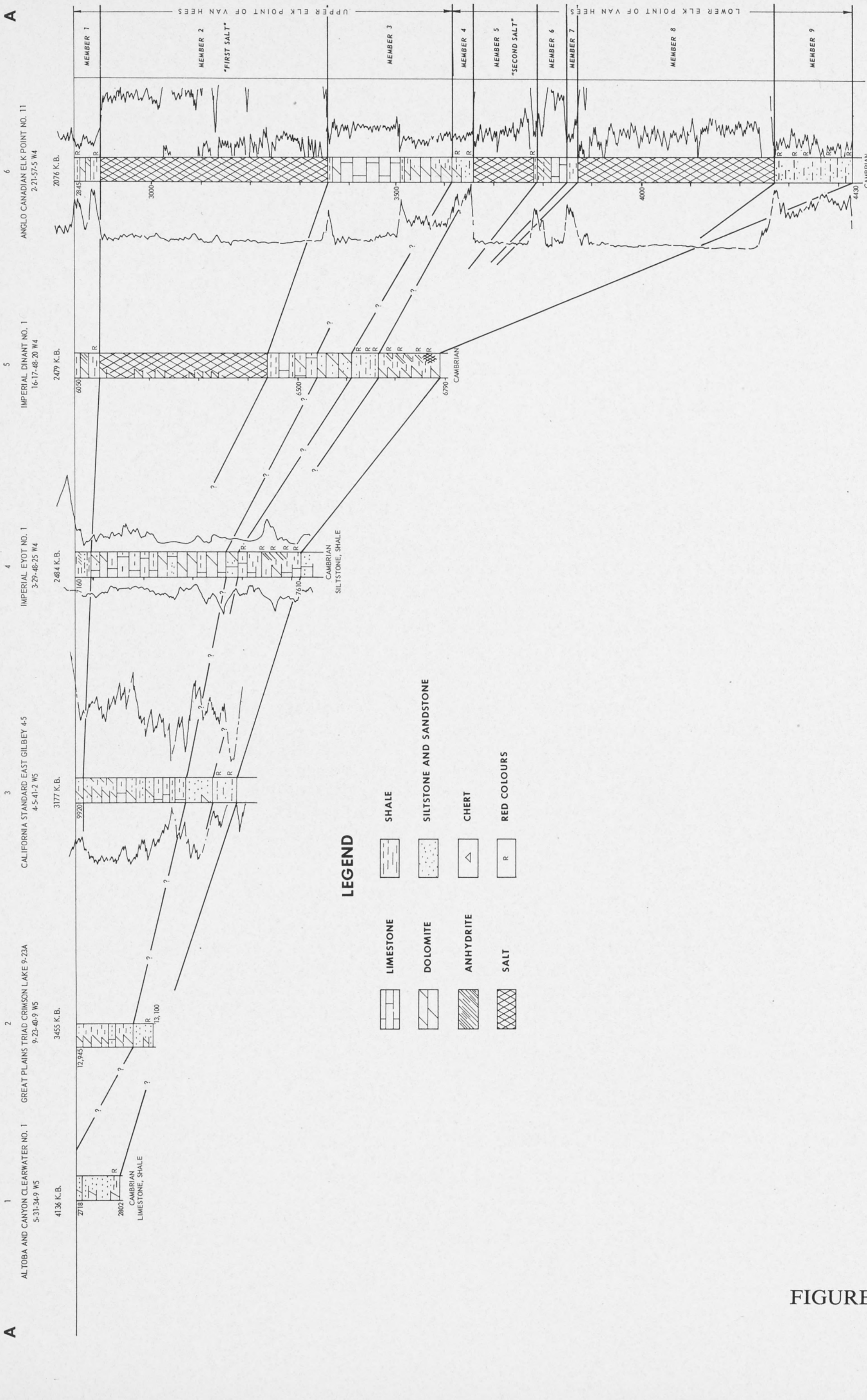
1 Published with permission of the Director, Geological Survey of Canada, Ottawa. This is an abstract of a paper presented before the Petroleum Natural Gas Division of the Canadian Institute of Mining and Metallurgy at the Tenth Annual Technical Meeting at Edmonton, Alberta, May 13-15, 1959.

2 Geologist, Geological Survey of Canada, Calgary, Alberta.



A
A
ALTOBA AND CANYON CLEARWATER NO. 1
5-31-34-9 W5
4136 K.B.
2718
2802
CAMBRIAN
LIMESTONE, SHALE
GREAT PLAINS TRIAD CRIMSON LAKE 9-23A
9-23-40-9 W5
3455 K.B.
12,945
13,100
CALIFORNIA STANDARD EAST GILBEY 4-5
4-5-41-2 W5
3177 K.B.
9920
IMPERIAL EYOT NO. 1
3-29-48-25 W4
2484 K.B.
7160
7610
CAMBRIAN
SILTSTONE, SHALE
IMPERIAL DINANT NO. 1
16-17-48-20 W4
2479 K.B.
6050
6500
6790
CAMBRIAN
ANGLO CANADIAN ELK POINT NO. 11
2-21-57-5 W4
2076 K.B.
2845
3000
3500
4000
4430
CAMBRIAN
SILTSTONE,
SHALE
UPPER ELK POINT OF VAN HEES
LOWER ELK POINT OF VAN HEES
MEMBER 1
MEMBER 2
"FIRST SALT"
MEMBER 3
MEMBER 4
MEMBER 5
"SECOND SALT"
MEMBER 6
MEMBER 7
MEMBER 8
MEMBER 9
LEGEND
LIMESTONE
DOLOMITE
ANHYDRITE
SALT
SHALE
SILTSTONE AND SANDSTONE
CHERT
RED COLOURS

FIGURE 2

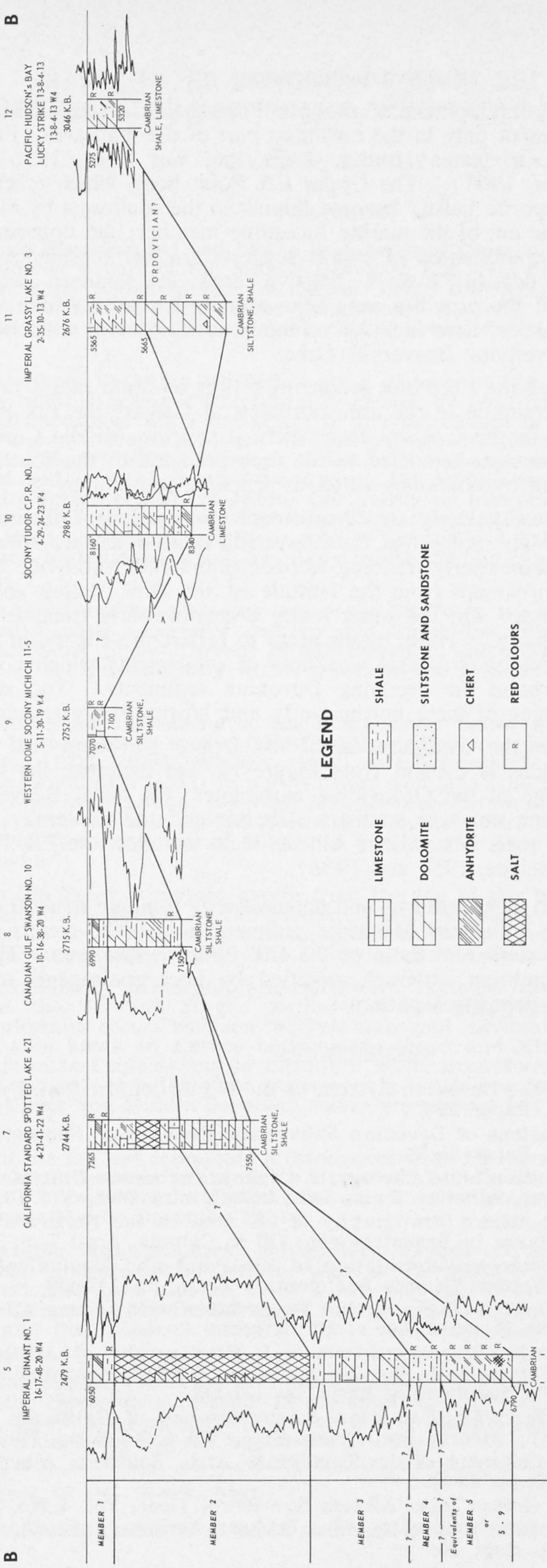

B
B
5
IMPERIAL DINANT NO. 1
16-17-48-20 W4
2479 K.B.
6050
6790
CAMBRIAN
7
CALIFORNIA STANDARD SPOTTED LAKE 4-21
4-21-41-22 W4
2744 K.B.
7265
7550
CAMBRIAN SILTSTONE, SHALE
8
CANADIAN GULF SWANSON NO. 10
10-16-38-20 W4
2715 K.B.
6990
7150
CAMBRIAN SILTSTONE SHALE
9
WESTERN DOME SOCONY MICHICHI 11-5
5-11-30-19 W4
2752 K.B.
7070
7100
CAMBRIAN SILTSTONE, SHALE
10
SOCONY TUDOR C.P.R. NO. 1
4-29-24-23 W4
2986 K.B.
8160
8340
CAMBRIAN LIMESTONE
11
IMPERIAL GRASSY LAKE NO. 3
2-35-10-13 W4
2676 K.B.
5565
5665
CAMBRIAN SILTSTONE, SHALE
ORDOVICIAN?
12
PACIFIC HUDSON'S BAY
LUCKY STRIKE 13-8-4-13
13-8-4-13 W4
3046 K.B.
5275
5320
CAMBRIAN SHALE, LIMESTONE
MEMBER 1
MEMBER 2
MEMBER 3
MEMBER 4
Equivalents of MEMBER 5 or 5 - 9
LEGEND
LIMESTONE
DOLOMITE
ANHYDRITE
SALT
SHALE
SILTSTONE AND SANDSTONE
CHERT
RED COLOURS

FIGURE 3

Basin Development

Some inference as to the development of the Elk Point basin of deposition can be made. The Lower Elk Point beds, present only in the northeast part of the map-area (Fig. 1), terminate against truncated Ordovician carbonates (Buller, 1958, and van Hees, 1956), or else, they change facies eastward (Walker, 1957). The Upper Elk Point beds, which reach a thickness of about 700 feet within the 'evaporite basin,' become thinner to the southwest by rapid pinch-out of the salt member and by wedging out of the marine limestone member; the uppermost member being the most extensive. This combination of events suggests gradual subsidence permitting progressive onlap of Elk Point deposits over a positive area in southern and southwestern Alberta. The southern part of the province may have remained relatively high into Upper Devonian time and some shelf clastics, here included on the basis of lithology with the Elk Point, may in fact be equivalent to the overlying Beaverhill Lake.

There is some evidence that the Elk Point sediments reflect to some extent the topography of the underlying surface. For example in the area northeast of Calgary the Elk Point is thin over Upper Cambrian, but thicker in the Calgary area where it overlies Middle Cambrian (Fig. 1). Thick Lower Elk Point sediments are restricted to the area bounded to the southeast by Ordovician carbonates and to the west by dolomites dated as Upper Cambrian by de Mille (1958).

Both northeasterly and northwesterly structural trends seem to have influenced the configuration of the Elk Point basin. The margin of the Lower Elk Point in eastern Alberta has a northeast depositional strike and northeasterly trending isopach thin trends subdivide the positive area of southern Alberta. One thin extends from the latitude of the Bow Valley and one from the southwest corner of the province. On the other hand, a northwesterly trend is apparent in the west margin of the 'evaporite basin.' These trends seem to reflect pre-Elk Point features, in part erosional, but possibly indicative of structural weakness or movements which controlled the depositional and erosional patterns of the overlying Devonian sediments. The southern Alberta arch may result from the crossing of these northeasterly and northwesterly trending elements.

Some correlation between the configuration of the Upper Devonian reef chains and the trends of the Elk Point isopachs is evident from Figure 1. For example, the shelf-margin reef complex follows the wedge-edge of the Ordovician carbonates; the basal Beaverhill Lake reefs seem to follow Elk Point isopach trends in southern Alberta; and the Duvernay embayment and flanking Cairn stromatoporoid reefs in southern Alberta seem to follow the Elk Point embayment north of the Princess area. (Belyea, 1957 and 1958).

Tovell (1958) pointed to northeasterly and northwesterly trending structural elements south of the 51st Parallel as having influenced Mesozoic sedimentation. The trends of the structure contours on Tovell's maps are similar to those of the Elk Point in this area. This suggests that early structures, possibly Precambrian, although modified by later epeirogenic movements, have influenced later erosional and deposition patterns.

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BASAL UPPER DEVONIAN STRATA BETWEEN DRUMHELLER AND ROCKY MOUNTAINS, ALBERTA

TARAS P. STOREY [1]

Abstract

The basal Upper Devonian red bed in the area between Drumheller and the Rocky Mountains commonly is considered a part of the Middle Devonian Elk Point formation [2]. This "correlation" is perpetuated from early considerations (McGehee, 1949; Imperial Oil, 1950) which assigned the red bed interval to the Elk Point on the questionable basis of alleged lithologic similarity and presumed analagous stratigraphic position. These considerations are untenable for the following reasons:

(a) The basal Upper Devonian red bed is not a part of the Elk Point but is naturally separated from it by a notable regional unconformity caused by pre-Upper Devonian erosion of 50 to 800 or more feet of uppermost Elk Point strata in the subsurface of Western Canada. This unconformity is interpreted from evidence in the published cross-sections of Crickmay (1954), Law (1955), and van Hees (1956). Although these authors themselves did not interpret the contact below the red bed interval as an unconformity, the obvious structure in the Elk Point strata and suggested differential erosion of these, can hardly be interpreted otherwise. This natural and significant break in sedimentation between Upper and Middle Devonian strata has long been known from the lower MacKenzie River area to Great Slave Lake (Cooper, et al, 1942), and has been recognized and agreed upon by many in the region of the Mississippi Valley (Illinois State Survey, 1944).

(b) Thus, the red bed is not the same age as the Elk Point, nor is it the same age everywhere as it is trangressive with successive conformable Upper Devonian (Beaverhill Lake) strata, which rest unconformably upon different Middle Devonian and older rocks. The red bed is, thus, itself an indicator of the unconformity which separates the rocks of the Upper and Middle Devonian Epochs.

(c) The red bed is not traceable into Elk Point strata below the unconformity, but rather in different areas it corresponds to the following Upper Devonian formations, — Ghost River formation of Walcott, (1923, 1928), Warren (1927) in the frontal Rocky Mountains west of Calgary; Unit C of Sloss and Laird (1947) in northwestern Montana; the Mafeking formation of Crickmay (1954) in outcrops in Manitoba; the Watt Mountain formation of Law (1955) in northern and central Alberta;the 'first red bed' of van Hees (1956) in the subsurface across Saskatchewan, as well as his interval from the top of 'first red bed' to the base of the 'second red bed' in western Saskatchewan.

The top of the Elk Point is revised herein from the top of the basal trangressive red bed of the Upper Devonian to the bottom of the interval. This boundary coincides with the regional unconformity which in every respect is a more significant horizon for both formational and stratigraphic subdivision and nomenclature. The following points will illustrate this argument:

(a) It is fundamentally unacceptable to consider a 'regional' hiatus within the rocks of one stage for example, the Givetian Stage. Rather it is basically sound, in theory and in practice, that such an unconformity occurs between the Frasnian and Givetian Stages. These mark the natural unconformable break in Europe between the Upper and Middle Devonian Series (Schindewolf, 1954). It is in fact misleading to include a major unconformity within one formation as it is generally understood! It is therefore unreasonable to use one formational name which hides the fact that both Upper and Middle Devonian strata are present but separated by a regional unconformity.

(b) The top of the red bed represents a transgressive facies boundary and therefore cannot represent a time-marker between strata of the Upper and Middle Devonian Epochs. This red bed cannot be considered to represent late Middle Devonian sediments, when in fact below the red bed are late and early Middle Devonian strata.

(c) Many notable stratigraphers deliberately include (Woodring, 1953), or unsuspectingly hide regional unconformities within type or reference sections. An example is the Cedar Valley formation of Iowa (Cooper, 1942) which has led to unceasing arguments that this formation is either Upper or Middle Devonian in age. In fact, the Cedar Valley is Upper and Middle Devonian and the "hidden" unconformity is well known beyond the area of the type section.

This same stratigraphic procedure has been followed in Western Canada, and has been commonly applied to the Devonian succession in the subsurface between Drumheller and the frontal Rocky Mountains. There is every reason to refer to the basal Upper Devonian red bed of this area as basal Beaverhill Lake and not uppermost Elk Point.

---

1 Geologist, Canadian Husky Oil Ltd., Calgary, Alberta.

2 The term 'group' for the Elk Point is considered prematurely applied to the interval which is but slightly understood.

DEVONIAN REEF AND OFF-REEF RELATIONSHIPS IN THE DRUMELLER AREA

W. P. KIRKER [1]

ABSTRACT

Rapid facies changes associated with reef development occur in the Devonian Winterburn and Woodbend sediments of the Drumheller area. To indicate the facies relationships, the "Limy" and "Dolomitic" sediments are divided into several informal rock types. The "Dolomitic" sediments are classified according to their interpreted original or undolomitized rock types.

The Cooking Lake formation, composed of predominantly pelletoidal and fragmental limestones, forms the base of reef development in portions of the Southern Alberta Reef Complex. A line of organic shoals is indicated in the Cooking Lake, six to eight miles in front of the Reef Complex.

The Duvernay formation is closely associated with reef development. It is composed predominantly of reef detritus close to the Reef Complex and contains incipient reef developments in a lime mud facies beyond the detrital zone.

The Ireton formation is a lime mud facies with tongues of fragmental carbonate. The upper portion of the Ireton is dolomitic and contains a dark organic dolomite band which becomes the main constituent of the Ireton interval over the Reef Complex.

The Southern Alberta Reef Complex, an informal term used to designate the Woodbend carbonates of the southern portion of the study area, is composed of fragmental carbonate and reefoid beds. Organic material predominates in a band approximately 3 miles wide along the reef front.

The Nisku interval contains shoals of light organic dolomite with associated fossil fragmental dolomites and pelletoidal dolomites separated by intershoal areas of dark dolomitic muds and bedded dark organic dolomites.

The depositional environment of the sediments indicates a period of almost continuous reef growth modified by cycles of emergence and submergence. The emergence or lowering of the sea level is associated with erosion of the reef while the submergence was probably a period of rapid growth.

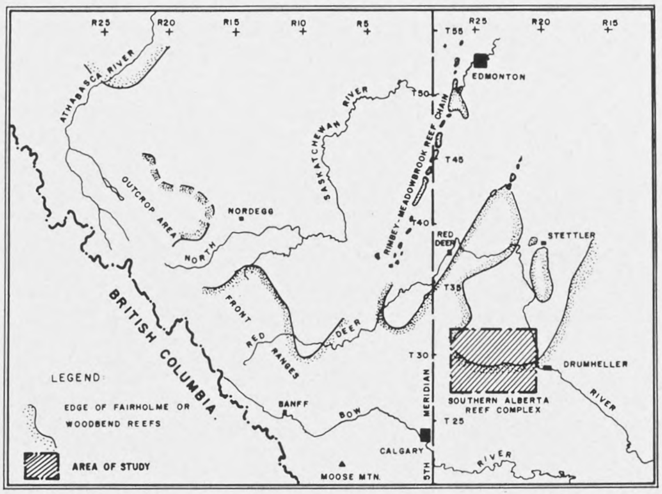


FIGURE 1

INTRODUCTION

The purpose of this paper is to describe the stratigraphy and facies relationships of the Upper Devonian Woodbend and Winterburn sediments in the Drumheller area (Fig. 1). In the Woodbend group, the area of study straddles the abrupt change of the carbonates of the Southern Alberta Reef Complex to the slightly more argillaceous off-reef sediments of the equivalent Cooking Lake, Duvernay and Ireton formations. In the Winterburn group the area is one of rapid facies changes which can be closely related to the underlying Woodbend features. In order to show the facies relationships of the dolomitized Winterburn and Woodbend sediments, an effort has been made to interpret the secondary dolomites as to their original rock types. The relationships, thus established are highly interpretive, and somewhat gross, since the original texture of the rocks and their organic constituents have been partly to completely obliterated by dolomitization. The depositional picture presented shows the Drumheller area to one of rapid change associated with reef and/or shoal developments in both the Woodbend and Winterburn.

---

1 Geologist, Texfel Corporation, Calgary, Alberta.

NOMENCLATURE

Although the Drumheller area is 120 miles from the Devonian type sections as proposed for the Edmonton area (Imperial Oil Limited, Geological Staff, 1950), the sediments of the area under study fit into this breakdown with some minor qualifications. The writer has therefore used this nomenclature for the Drumheller area realizing that:—

A. The Calmar silt of the Leduc area is probably not exactly the same silt zone as the "Calmar" silt of the Drumheller area. However the "Calmar" as used in this study is a consistent marker in the area and probably has much the same time connotation as the type Calmar, being the lowest consistent silt marker in a zone of silt and anhydrite deposits in the Winterburn.

B. The Nisku as described in the type section is not exactly the same time unit as the Nisku of the Drumheller area. That is, the Nisku of the Drumheller area, while it appears to be the same formation or rock unit as the Nisku of the Edmonton area, includes the Camrose tongue of the Ireton (Belyea 1958) which is definitely a pre-Nisku time-rock unit with similar lithology to the Nisku and indivisible from it in the Drumheller area.

C. The top of the Ireton of the Drumheller area, because of the above, is not the same time horizon as that in the type Ireton, but the Ireton is still a correlatable rock unit or formation. The Ireton of the Drumheller area pinches out entirely over the Woodbend reef and is no longer a recognizable unit south of the pinch-out.

D. The Duvernay as described at the type section is recognized in the Drumheller area as a slightly expanded unit. The petroliferous shale, which marks the top of the Duvernay is very irregular in its distribution in this area. However an operational unit can be picked using the top of the most consistent shale marker and extrapolating this marker into the wells in which it is absent.

E. The Cooking Lake formation, as described by Andrichuk (1958) for the Stettler area, is a recognizable unit in the Drumheller area. This unit is thought to be equivalent to the type section in the Calmont Leduc 3 well, although it differs slightly from the Cooking Lake as used in the Edmonton area by some workers. These latter include in the Cooking Lake the basal fragmental unit of the Duvernay formation of Andrichuk (1958). Since the Cooking Lake of Andrichuk forms the more consistent lithologic unit it has been adopted for this study.

The author's conception of the relationship of the above units with that of Belyea, and Andrichuk and Wonfor, is shown in Figure 2.

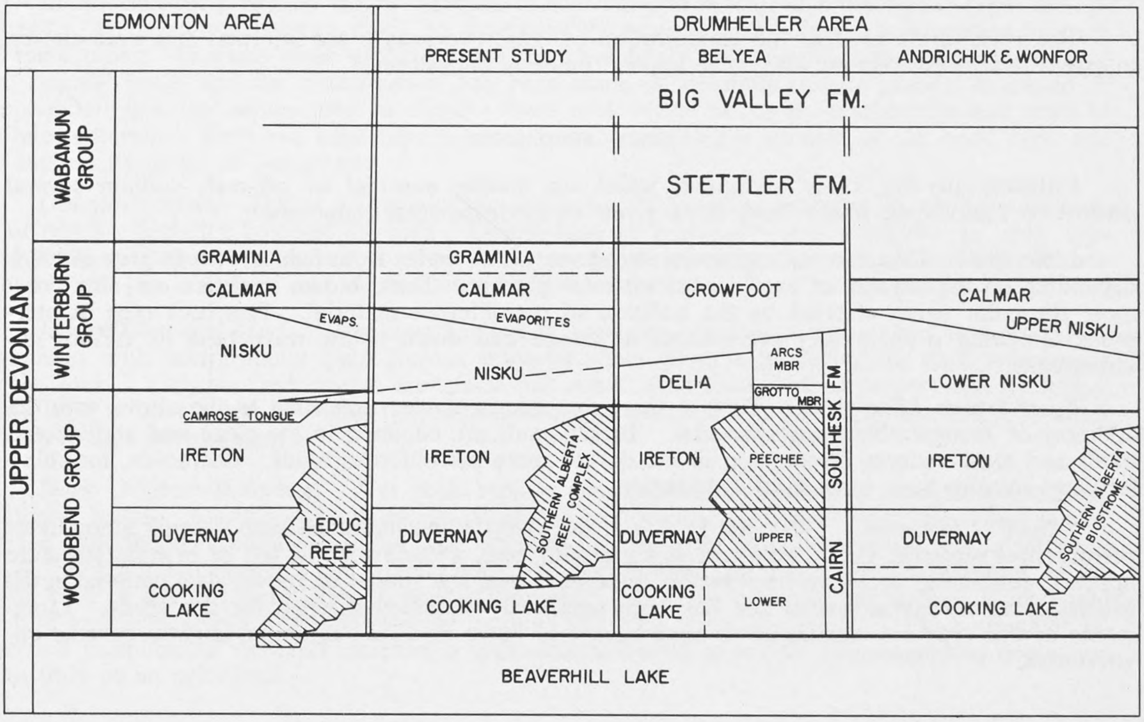


FIGURE 2

Since this is a local study and therefore restricted in its scope, the writer does not feel qualified to enter into the present controversy over the nomenclature for the Devonian of Alberta. The study however is located in the area of nomenclature overlap and it is hoped that this detailed stratigraphic analysis will help to resolve some of the problems.

The new units as proposed by Belyea (Belyea and McLaren, 1957) for southern Alberta deserve some comment as to their application in the area of study. These units were found useful near the southern edge of the report area but did not appear applicable in the main portion of the study. Dark coral beds of Grotto lithology were found both above and below the grey dolomites of the Arcs lithology with no obvious connection. This sporadic development of the Grotto lithology probaby represents a very local variation in the environment of deposition rather than a mappable unit.

The Delia formation, as previously proposed by Belyea (1955) is a valid unit but the implication that the Nisku equivalent is completely evaporitic in this area is not acceptable to the author.

The Upper Cairn, or "dark reef", appears to be more closely associated with the overlying beds of the "white reef" (Peechee) than with the underlying Lower Cairn (Cooking Lake). The Cooking Lake unit as used by Andrichuk (1958), Belyea (1958), is a consistent lithologic unit which can be easily separated from the overlying reef members of the Reef Complex, and from the basal fragmental unit of the Duvernay in the off-reef area.

It should be noted that the above comments pertain only to the area of the study and may not be valid when considering the rest of southern Alberta.

General Lithology

The sediments in the study area can be divided into two main groups which in turn can be subdivided into several rock types. They are:

1. The "Limy" sediments in which the original texture, composition and organic components can be readily seen and thereby classified.

2. The "Dolomitic" sediments in which much of the character of the original rock type is obscured by secondary dolomitization. The classification of these sediments is highly interpretive and somewhat generalized in that a great deal of the original organic material is indistinguishable and interpretation is based on vague indications.

The rock terms used in the classification of these two groups are informal and were chosen to give a descriptive picture with some implied mode of deposition.

LIMY SEDIMENTS

Lithologically the "Limy" sediments, which are mainly non-reef or off-reef, contain several distinctive rock types which have been given an environmental connotation.

Lime Mud: This is a microgranular limestone which varies from light brown to grey in color depending on the amount of argillaceous material present. Dark brown varieties are also common, the color being affected by the addition of petroliferous material. This rock type is interpreted as being a chemically precipitated limestone laid down below wave base in various environments.

Fossiliferous Lime Mud: This is the same microgranular limestone as the above with the addition of recognizable fossil material. Brachiopods are common in the clean and argillaceous muds and algal material is common in the darker more petroliferous muds. Ostracods, foraminifera and spicules have some local distribution.

"Algal" Limestone: This rock type is a microcrystalline limestone with varying amounts of petroliferous material. On etching and washing with acid, a meshwork or felt of organic structure appears, containing abundant fine tubules. In appearance, it is similar to known algal material in the Mississippian of Saskatchewan and has been tentatively classified as algal for this study. Limestones of this type are considered to have been laid down in a low agitation, slightly euxenic environment.

Pelletoidal Limestone: The pellets which comprise this rock type are usually dark in color, of microcrystalline texture and with good to only fair roundness. The pellets range in size from 0.5 to 1 mm and are usually cemented with clear calcite or spar. Inter-pellet porosity is common. The pellet limestones often contain small foraminifera and other organic bodies. Some of the pellets appear to be composed of the algal material mentioned above. There is a close association of the pellet and algal limestone types. Both would appear to have much the same environment of deposition with some slight increase in the amount of agitation in the case of the pellets.

Fossil Fragmental Limestone: The significant bioclastic material which comprises this rock type is used to further classify the fragmental limestones. The most important and significant for the purpose of the study are the stromatoporoid and coral fragmentals associated with reef development. The fragments are usually cemented with earthy microgranular limestone. The depositional environment for this rock type is obviously one of high agitation and oxygenation.

Lime Sand: This rock type is composed of grains of limestone too small to recognize as distinctly organic or inorganic but definitely of fragmental origin.

Earthy Limestone: This is a microgranular limestone which is characterized by its softness, earthy appearance, and excellent porosity but poor permeability. It is often difficult to distinguish between the earthy limestone and the lime mud. This rock type differs from the lime mud in that it is the end product of fragmentation, a mechanically derived rock. The environment of deposition is widespread since it was probably carried as a lime flour or milk over a considerable area before being deposited.

Stromatoporoid and Coral Limestones: This rock type is a lime mud containing abundant stromatoporoids or corals which are interpreted as having grown in place. The matrix of microgranular lime is usually clean or petroliferous with very little argillaceous material present. The fragments of the fine lattice of the stromatoporoids are usually associated with bits of coarse cellular structures interpreted as coral fragments. The algal material previously described is also found associated with the stromatoporoid limestone. This is considered an insipient reef-building unit laid down in a well oxygenated environment of little agitation.

Petroliferous Dark Shale: A brown shale characteristic of an euxenic environment with no agitation.

DOLOMITIC SEDIMENTS

In the dolomitic part of the Winterburn and Woodbend several distinctive rock types are apparent. An attempt has been made to determine the original rock before dolomitization for each of these types. In some cases dolomitization has completely obliterated all the characteristics of the original rock, and the classification has been made on dolomite texture alone. It should be emphasized that the names used to classify these rock types are highly interpretive and open to re-interpretation. They are used here to give a more descriptive picture of the rock type and to suggest its mode of deposition.

Dolomitic Mud: This is a fine sucrosic dolomite with varying amounts of argillaceous material which affects the color of the rock. Dolomitization is usually not complete in this type and fossil indications are common. This rock type is interpreted as being the dolomitized equivalent of both the lime mud and the fossiliferous lime mud of the "Limy" sediments.

Dark Dolomitic Mud: This classification is used for the fine sucrosic and fine-crystalline dolomites with intergranular petroliferous material which gives a homogeneous dark appearance to the rock. Organic components are sparse but some *Amphipora*-like structures can be found. This type is interpreted as being the dolomitized equivalent of the dark petroliferous lime muds of the euxinic environment.

Dark Organic Dolomite: This rock type is characterized by abundant recognizable organic material, usually *Amphipora* and corals, cemented with the dark dolomitic muds described above. In the Woodbend, dolomites of this type contain recognizable stromatoporoids and algal material. A gradation between the original rock and the dolomitized equivalent is common in the basal part of the Southern Alberta Reef Complex. This rock type can be further divided into reefoid and non-reefoid depending on the amount and type of fossil material. The amount of associated petroliferous material indicates a somewhat restricted or euxinic environment of deposition with little or no agitation.

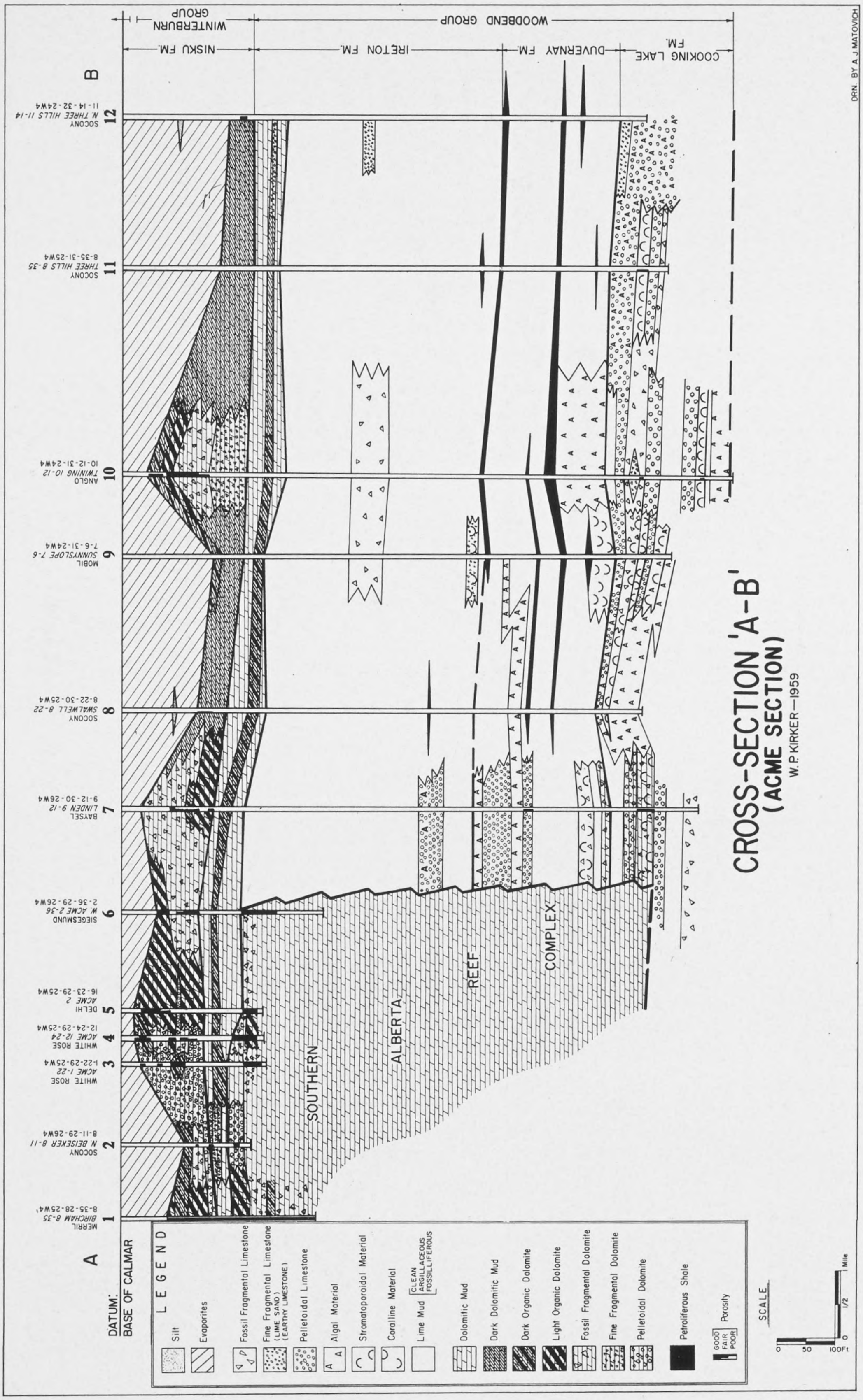

CROSS-SECTION 'A-B'
(ACME SECTION)
W. P. KIRKER—1959
DATUM: BASE OF CALMAR
LEGEND
Silt
Evaporites
Fossil Fragmental Limestone
Fine Fragmental Limestone (LIME SAND) (EARTHY LIMESTONE)
Pelletoidal Limestone
Algal Material
Stromatoporoidal Material
Coralline Material
Lime Mud CLEAN ARGILLACEOUS FOSSILLIFEROUS
Dolomitic Mud
Dark Dolomitic Mud
Dark Organic Dolomite
Light Organic Dolomite
Fossil Fragmental Dolomite
Fine Fragmental Dolomite
Pelletoidal Dolomite
Petroliferous Shale
GOOD FAIR POOR Porosity
SCALE
SOUTHERN
ALBERTA
REEF
COMPLEX
WINTERBURN GROUP
WOODBEND GROUP
NISKU FM.
IRETON FM.
DUVERNAY FM.
COOKING LAKE FM.
DRN. BY A. J. MATOVICH

FIGURE 3

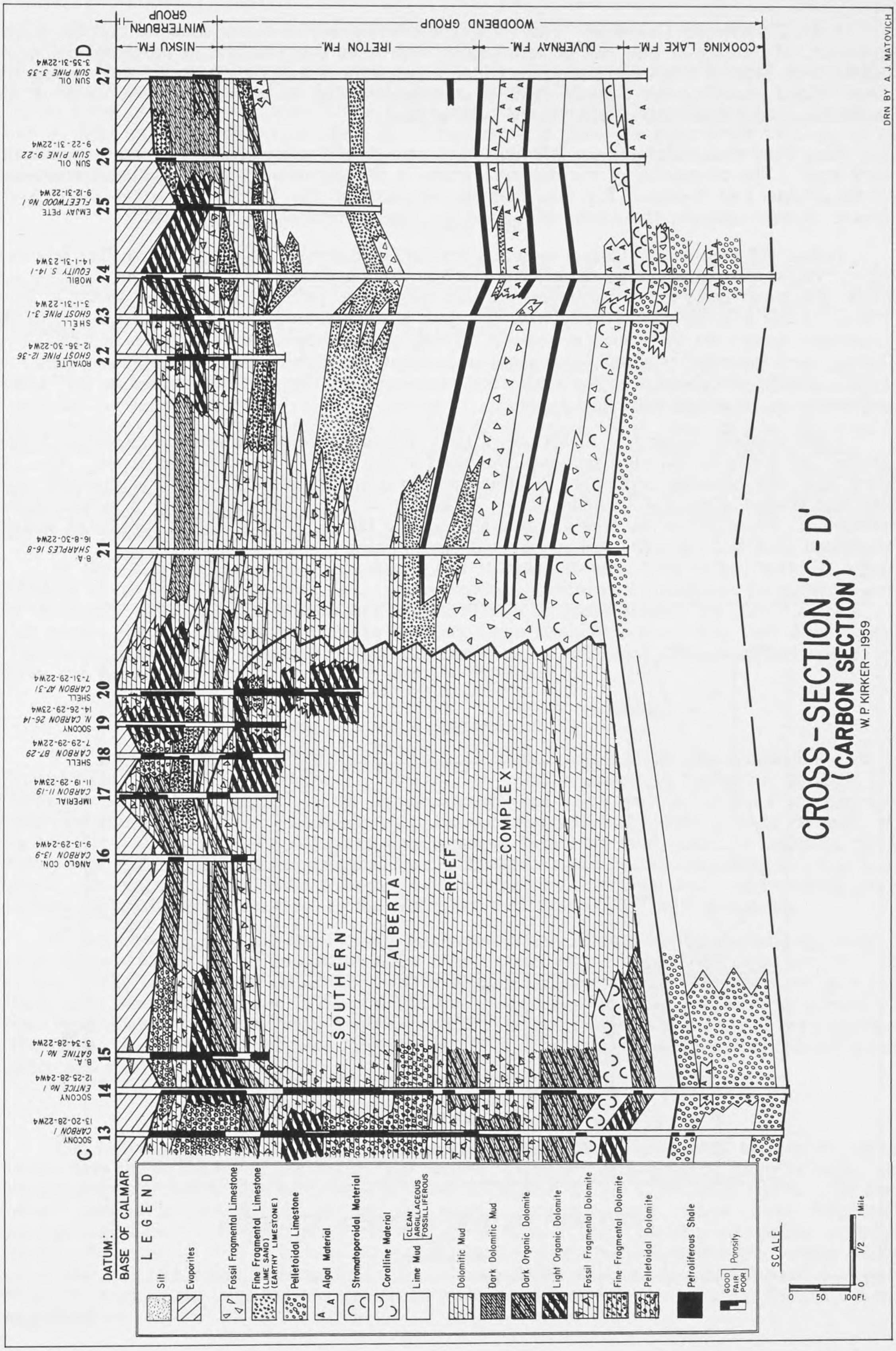

CROSS-SECTION 'C-D'
(CARBON SECTION)
W. P. KIRKER—1959
DRN BY A. J. MATOVICH
DATUM: BASE OF CALMAR
LEGEND
Silt
Evaporites
Fossil Fragmental Limestone
Fine Fragmental Limestone (LIME SAND) (EARTHY LIMESTONE)
Pelletoidal Limestone
Algal Material
Stromatoporoidal Material
Coralline Material
Lime Mud
CLEAN ARGILLACEOUS FOSSILIFEROUS
Dolomitic Mud
Dark Dolomitic Mud
Dark Organic Dolomite
Light Organic Dolomite
Fossil Fragmental Dolomite
Fine Fragmental Dolomite
Pelletoidal Dolomite
Petroliferous Shale
GOOD FAIR POOR Porosity
SCALE
0 50 100Ft.
0 1/2 1 Mile
WINTERBURN GROUP
WOODBEND GROUP
NISKU FM.
IRETON FM.
DUVERNAY FM.
COOKING LAKE FM.
SOUTHERN ALBERTA REEF COMPLEX
C
D
13 SOCONY CARBON I 13-20-28-22W4
14 SOCONY ENTICE No I 12-25-28-24W4
15 B.A. GATINE No. I 3-34-28-22W4
16 ANGLO CDN. CARBON 13-9 9-13-29-24W4
17 IMPERIAL CARBON 11-19 11-19-29-23W4
18 SHELL CARBON B7-29 7-29-29-22W4
19 SOCONY N. CARBON 26-14 14-26-29-23W4
20 SHELL CARBON A7-31 7-31-29-22W4
21 B.A. SHARPLES 16-8 16-8-30-22W4
22 ROYALITE GHOST PINE 12-36 12-36-30-22W4
23 SHELL GHOST PINE 3-1 3-1-31-22W4
24 MOBIL EQUITY S. 14-1 14-1-31-23W4
25 EMJAY PETE FLEETWOOD No. I 9-12-31-22W4
26 SUN OIL SUN PINE 9-22 9-22-31-22W4
27 SUN OIL SUN PINE 3-35 3-35-31-22W4

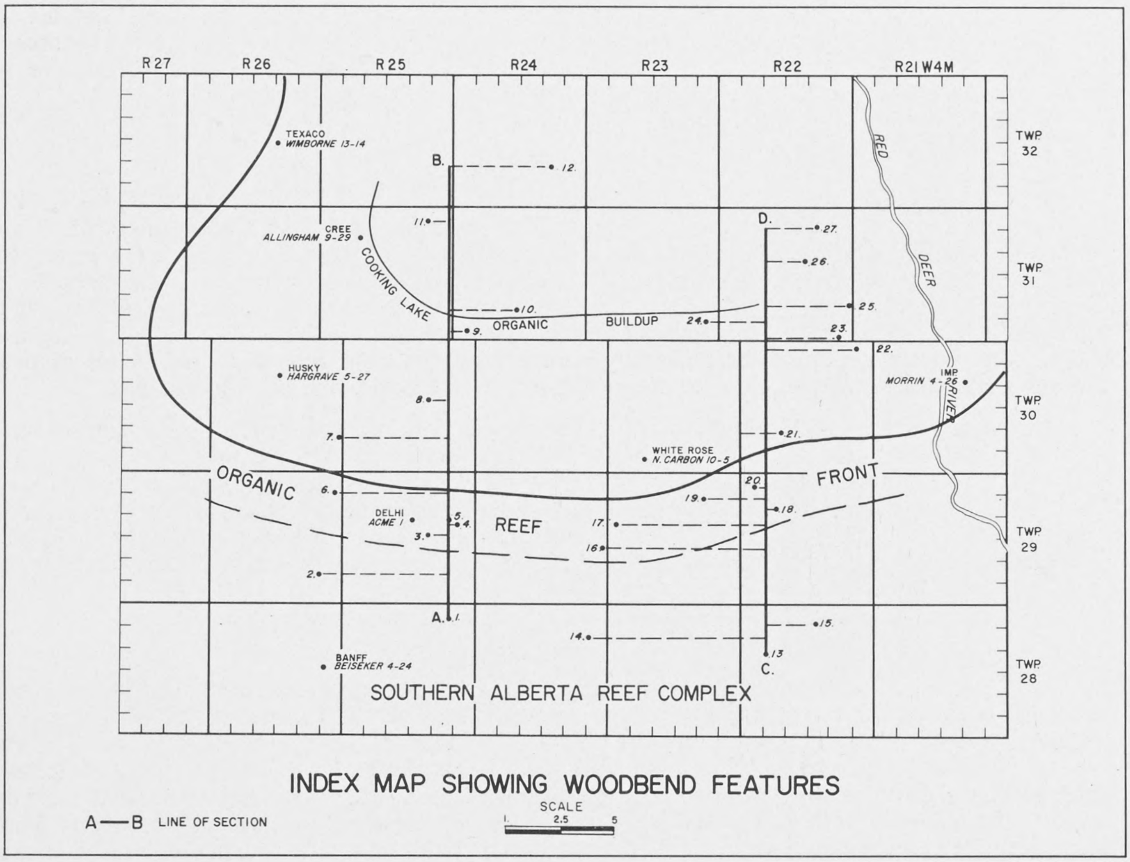
FIGURE 4

Fossil Fragmental Dolomite: This rock type is composed of coarse euhedral crystals of light dolomite, which may or may not be interlocked, with some fine anhedral to subhedral dolomites. Shadows or lines of fossil fragments are common when the fragments are etched and washed with acid. Good porosities are typical. This is considered to be the dolomitized equivalent of the fossil fragmental limestone of the "Limy" sediments.

Fine Fragmental Dolomites: Medium to coarse-grained sucrosic dolomite characterizes this rock type. The coarseness of the dolomite grains is thought to indicate the probable coarseness of the original rock texture. The lime sand classification of the limestones would produce the coarse sucrosic texture, the earthy limestone the fine to medium sucrosic texture.

Pelletoidal Dolomite: Coarse euhedral crystals of dolomite also characterize this lithologic unit. Vague rounded shadows of pellet boundaries, and generally poor porosity are used to separate this group from the *fossil fragmental dolomite*. The pelletoidal limestone which is interpreted as the original rock type of this dolomite is thought to differ in several ways from the pelletoidal limestones mentioned previously. These pellets appear to be larger in size (1 to 2 mm.) and deposited in a well oxygenated environment of high to medium agitation. This rock type is closely associated with the fragmental types whereas the pellets described in the "Limy" sediments are associated with algal material.

Light Organic Dolomite: A mixture of light colored medium grained sucrosic and fine-grained subhedral to anhedral dolomite was used as the criterion for this subdivision. The sucrosic dolomite probably represents the fine-fragmental infilling around the organic material, while the fine-grained subhedral dolomite seems to be the result of dolomitization of dense organic structures. Porosities in this type are generally poor to fair. The rock unit is considered reefoid, deposited in a well agitated, well oxygenated environment.



INDEX MAP SHOWING WOODBEND FEATURES

FIGURE 5

Facies Distribution and Relationships

The facies relationships of the area of study are shown on two south-north cross-sections A-B, the "Acme Section", (Fig. 3) and C-D, the "Carbon Section", (Fig. 4). The sections were drawn south-north perpendicular to the facies strike and the wells were then projected on to this line at right angles as shown in Figure 5. These sections show the generalized lithology of the significant units with some grouping of rock types for clarity. The wells have been given reference numbers for use in the discussion.

Cooking Lake

The Cooking Lake in the area of study is a consistent unit composed of pelletoidal and algal limestones with bands of stromatoporoidal and coral lime muds and fragmentals. Some bedded anhydrite is found in the lower sub-unit. For a detailed description of this formation the reader is referred to Andrichuk (1958), and Belyea (1956).

In the "Acme Section" the Cooking Lake is predominantly an algal lime mud at the northern end. To the south, at the Mobil Sunnyslope well (9), there is a conspicuous build-up of organic material (stromatoporoid and coral fragmental) coincident with a similar build-up in the overlying Duvernay unit. This would mark the edge of an organic shoal, after the principles used by Andrichuk (1958). Behind this shoal, in the intershoal area, algal material predominates. At the Baysel Linden well (7), approximately 2 miles north of the reef edge, there is another conspicuous build-up of dolomitized organic fragmental and pellet material. The fragmental carbonates appear to be reef detritus, and are probably derived from the initial reef development along the frontal organic belt of the Reef Complex.

In the "Carbon Section", the northern end is again an algal lime facies, with an organic build-up at the Mobil Equity well (24). This bedded incipient reef is replaced by pellet material to the south. The pelletoidal limestones predominate in the wells beneath the Reef Complex. In this section there is no indication at the Cooking Lake level, of approaching reef development. This would indicate that the reef did not start to grow at the same time along the entire reef front but varied from late Cooking Lake to early Duvernay.

Duvernay

The Duvernay sediments differ very little from those described in the Edmonton area by Imperial Oil Limited, Geological Staff (1950). The normal section is composed of dark lime muds and petroliferous shales. In the "Acme Section" the lower portion of the Duvernay consists predominantly of dense lime muds which change to organic fragmentals close to the reef. An incipient reef development composed of coral material in a lime mud matrix is indicated at the Sunnyslope well (9). This development was probably localized by the underlying Cooking Lake shoal. The upper portion of the Duvernay is predominantly dark lime mud and bands of petroliferous shale which change, close to the reef edge, to pelletoidal and algal limestones.

In the Carbon area, the Duvernay is composed mainly of reef detrital material deposited in large tongues which extend outward 6 miles from the reef edge. Beyond this point the Duvernay is very similar to that of the Acme area, with indications of incipient reef development in a predominantly lime mud facies. The petroliferous shales are widespread and fairly consistent but local developments do occur. These shales appear to be end members in a cycle of sedimentation. The shales, indicating submergence, separate bands of carbonate deposition associated with emergence and erosion of the reef.

Ireton

The Ireton sediments of the area of study are generally less argillaceous and more petroliferous than the sediments of the Ireton type section. Tongues of fragmental material which can be traced over a considerable area, are a common constituent of the Drumheller Ireton. The fragmental material is derived from the reef and grades outwards from coarse fossil fragmental through lime sand to earthy limestone. In the "Acme Section," algal material and pellets are found close to the reef edge with an isolated body of fragmental limestone indicated at the Socony Sunnyslope well (9) and Anglo Twining well (10). It is possible that this fragmental band is a westward extension of the large fan of reef detrital material indicated in the "Carbon Section" at this same horizon.

The Upper Ireton contains a dolomitized unit which varies considerably in thickness. A widespread band of *dark organic dolomite* is a prominent feature of this upper Ireton sub-unit. Over the Reef Complex the argillaceous dolomites, typical of the Ireton, pinch out and the *dark organic dolomite* predominates. Locally this organic mud unit is replaced with *fine fragmental dolomite* and dolomitized light colored fossiliferous muds.

In the "Carbon Section," the upper dolomitized sub-unit of the Ireton expands at the B.A. Sharples well (21) until it includes almost the complete Ireton. This can probably be explained by the abundance of permeable coarse fragmentals in the section which would transmit any dolomitizing solutions affecting the reef proper, outward into the off-reef sediments. In this "Section" the *dark organic dolomite* band of the upper sub-unit has been replaced locally by fragmentals.

SOUTHERN ALBERTA REEF COMPLEX

This term as used in the study indicates the complex relationship of the organic reefs, associated fragmental rocks and evaporites of the southern Alberta Woodbend sediments.

The sediments of this unit are almost completely dolomitic and therefore the interpreted rock types are indicated on the sections. Although the well control is poor for this unit some facies relationships are evident.. A belt approximately 3 miles wide along the Reef Complex front (Fig. 5) has a high percentage of *organic dolomites* in the upper part of the unit. To the south or behind this belt the equivalent section is predominantly *fragmental and pelletoidal dolomites.*

The *dark organic dolomites,* typical of the "Brown Reef" of the mountain sections and the Upper Cairn formation of Belyea and McLaren (1957) are found in the lower part of this unit. The bands of bedded *dark organic dolomite* do not appear to be consistent over any wide area but are replaced either, more or less abruptly by fragmental types typical of the upper unit or gradationally by their undolomitized equivalent, the dark stromatoporoid and coral limestones.

NISKU

In the study area, as in the Edmonton area, the Nisku underlies the Graminia and Calmar silt and anhydrite units, and overlies the Ireton argillaceous dolomite and limestone rock unit. The Nisku at Drumheller can be subdivided into an upper evaporitic sub-unit, and a lower secondary dolomite sub-unit. The Nisku evaporites consist of primary dolomite, anhydrite and dolomitic anhydrite with minor amounts of argillaceous anhydrite, anhydritic shale and silt. A detailed analysis of this sub-unit was not attempted but it is felt that a study of these sediments would show facies variations related to features of the underlying dolomite sub-unit. For example, a marked increase in the amount of argillaceous anhydrite, shale, and silt were noted, associated with the intershoal areas of the underlying dolomite unit. The Nisku dolomites have been treated in the same manner as the Woodbend dolomites with the interpreted original rock types and their relationships indicated on the cross-sections. The Nisku dolomite interval exhibits several depositional features (Fig. 6).

The Intershoal Basin: This is an area where the Nisku dolomites are thin and composed of *dark dolomitic muds* and minor developments of *dark organic dolomites* not generally reefoid in character. To the north, beyond the area of study, this unit is replaced locally by evaporites (Andrichuk and Wonfor, 1954).

Frontal Shoal Area: The shoals which develop in this zone are composed of light colored dolomites interpreted as being organic reef building structures and associated fragmental carbonates. This shoal development is thought to occur as a thin band sub-parallel with the Reef Complex. It is interesting to note the rough coincidence of these shoals with the shoal developments in the Cooking Lake, Duvernay and Nisku.

Inter Shoal Area: This feature is characterized by the development of an argillaceous dolomite or dolomitized lime mud with minor bands of *dark dolomitic mud.*

Main Shoal Area: This Nisku shoal development is associated very closely with the underlying Woodbend reef complex. The Main Shoal (Fig. 6) can be further subdivided into:—

(a) Fore-reef fragmental zone.
(b) Organic build-up or core.
(c) Back reef fragmental zone.
(d) Back reef pellet zone.

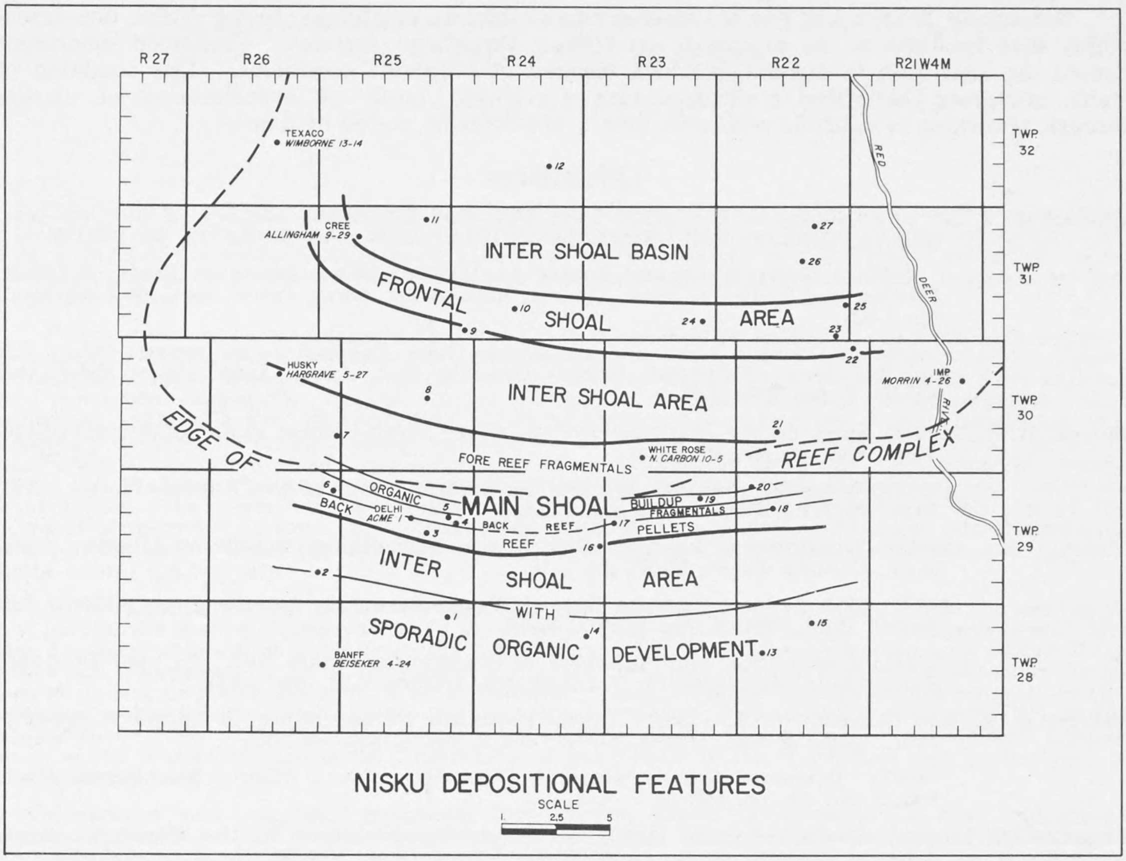


FIGURE 6

Inter Shoal Area of Sporadic Organic Developments: This area lies behind the Main Shoal and is separated from it by a zone of *fine fragmental dolomites,* clastics and bedded *dark organic dolomites.* In this area of sporadic organic developments, which will probably have considerable areal extent to the south, the classification of Belyea (1957) has considerable interpretative value if the Arcs is considered the *organic dolomites or fossil fragment dolomites* and the Grotto, the *dark dolomite muds and dark organic dolomite.*

CALMAR AND GRAMINIA

The Nisku in the Drumheller area is overlain by a section of silt and anhydrites approximately 50 feet thick. The lowest consistent silt band has been picked as the datum for the cross-sections and has been tentatively named the Calmar. This zone of silt and anhydrite occupies the same stratigraphic position as the combined Calmar and Graminia formations of the Edmonton area. This unit has not been studied in detail and is mentioned here only for the sake of completeness as it overlies the beds studied.

DEPOSITIONAL HISTORY

An interpretation of the depositional history of the area can be summarized as follows:—

The Cooking Lake was deposited in widespread seas of low agitation with some local shoal development. These shoals spread laterally establishing the reef front during early Duvernay deposition. Once reef growth had commenced it continued in a pulsating fashion with periods of relative emergence and submergence. The periods of emergence produced fragmental material, both in front and behind the reef core. In front of the reef the fragmental material was deposited in tongues or fans probably associated with surge channels. The periods of submergence produced dark organic strata behind the reef front, and dense limes and petroliferous shale in front of the reef. Submergence towards the end of Woodbend deposition resulted in the argillaceous beds of the Ireton over the Reef Complex, and the widespread band of *dark organic mud.*

Subsequent lowering of the sea level produced reefing conditions during Nisku deposition, which were localized by the previously established Woodbend features. Continued emergence caused the restriction in circulation which resulted in evaporitic conditions. This condition of stable emergence culminated in silt deposition, a probable result of concentration of clastics through reworking of soluable sediments over a considerable period of time.

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FACIES ANALYSIS OF UPPER DEVONIAN WABAMUN GROUP IN WEST-CENTRAL ALBERTA

JOHN M. ANDRICHUK [1]

Abstract

The Wabamun group, consisting mainly of carbonate rocks and anhydrite, increases in thickness westward from less than 500 feet in the Leduc and Stettler areas to approximately 1,800 feet in parts of the Rocky Mountains of Alberta where it is known as the Palliser formation. East of Leduc and north of Stettler, the Wabamun has been partially or completely removed by pre-Cretaceous erosion.

For purposes of facies analysis, the Wabamun is subdivided into four units that are believed to represent distinct rock sequences in parts of the area. These are basal, lower-middle, upper-middle and upper Wabamun. Because satisfactory marker beds occur only at the base and top and not within the group, an operational subdivision is employed based on the assumption that thickness variations are primarily the result of differential subsidence during deposition (excluding effects of later solution of evaporites). Thus, within any given time interval the thickness of rocks deposited should exhibit a constant proportion to the overall Wabamun thickness. The basal Wabamun includes the lowermost evaporitic interval and lateral marine carbonate equivalents. The lower-middle Wabamun represents the overlying interval to the top of the "Crossfield member" in the Calgary area. The upper-middle Wabamun includes post-"Crossfield" and pre-Big Valley beds; the upper Wabamun represents the Big Valley formation and approximate lateral equivalents.

Three main facies provinces are recognized, namely, evaporites and dolomites in the southeastern part of the map-area, limestones in the northwestern part (and locally at the southwest), and fine to coarse-crystalline dolomite in the intervening area. The microcrystalline and earthy dolomites are interpreted to be of secondary or diagenetic origin whereas the cryptocrystalline translucent dolomites are considered to be of probable primary origin. The limestones range from calcilutites to calcarenites and exhibit incipient dolomitization that commonly imparts a mottled appearance to the rock. The carcarenites are generally of the pseudo-oolitic or pelletoid type in most of the Wabamun; bioclastic limestone is characteristic of the uppermost unit and locally of the lower beds.

Evaporites and associated extremely fine-textured dolomites represent the most widespread distribution in the basal Wabamun. The main evaporites extend northwest through Stettler to Leduc whereas the extremely fine-textured dolomites occur farther northwest. In the middle Wabamun, the evaporites terminate a relatively short distance northwest and north of Stettler. Originally these evaporites may have extended north beyond their present limit but were probably removed by solution and pre-Cretaceous erosion. During deposition of the basal and upper Wabamun units, a subsidiary evaporite province occurred in the Foothills belt west of Calgary and may have extended north as far as the Clearwater River.

Beales (1956) originally noted the similarity of Palliser limestones of southwestern Alberta to those presently being deposited on the Bahama Banks. Pelletoid limestones are also characteristic of the Wabamun to the northwest of the Conference area, and although dolomitization has destroyed or obscured the original limestone texture in other sections, relicts of calcarenite texture in some dolomites suggest that widespread bank conditions existed in the Wabamun sea. Sutterlin (1958) described the mechanism by which these rapidly growing banks restricted free circulation of marine waters eastward, causing evaporite precipitation in the Stettler-Drumheller area.

Petroleum has accumulated in two main types of stratigraphically controlled traps within the Wabamun group. Facies change from porous secondary dolomites to relatively non-permeable equivalents approximately up-dip regionally (mainly eastward) is responsible for gas entrapment in the Okotoks-East Calgary-Olds trend of fields. In the Edmonton area, oil and gas are localized in erosional hills made up of porous Wabamun dolomites at the pre-Cretaceous unconformity.

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1 Andrichuk and Edie, Consultants, Calgary, Alberta.

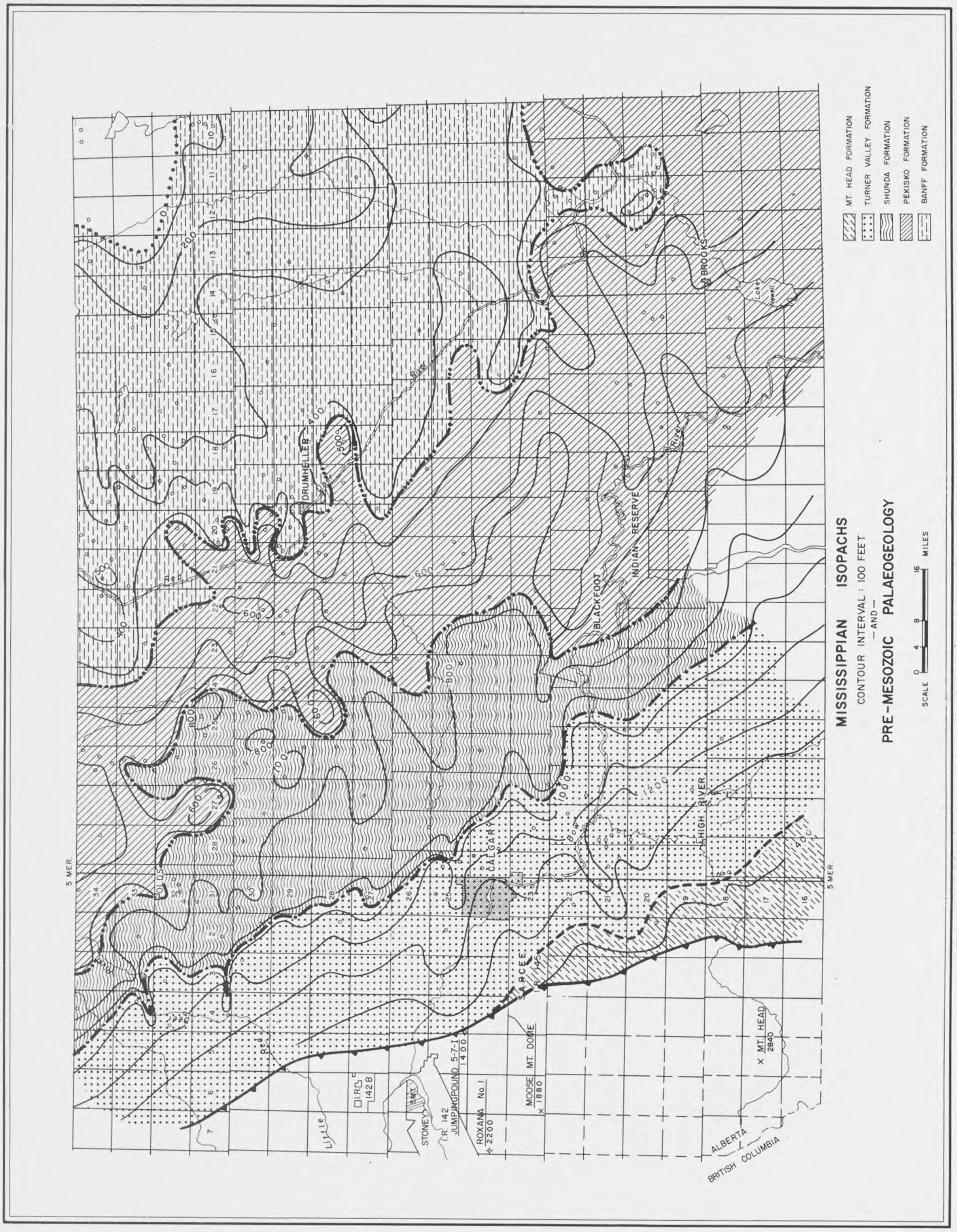

MISSISSIPPIAN ISOPACHS
CONTOUR INTERVAL : 100 FEET
— AND —
PRE-MESOZOIC PALAEOGEOLOGY
MT. HEAD FORMATION
TURNER VALLEY FORMATION
SHUNDA FORMATION
PEKISKO FORMATION
BANFF FORMATION
SCALE
MILES
DRUMHELLER
BROOKS
BLACKFOOT
INDIAN RESERVE
CALGARY
HIGH RIVER
MOOSE MT. DOME
ROXANA No. I
JUMPINGPOUND 5-7-1
STONEY
MT. HEAD
ALBERTA
BRITISH COLUMBIA
5 MER.

FIGURE 2

MISSISSIPPIAN OF SOUTH-CENTRAL ALBERTA

D. G. PENNER [1]

Abstract

Mississippian rocks are truncated in a northeast direction across the map-area. The erosional limits of the various formations are shown.

The Bakken is thickest in the east part and thins northward and westward, where only the lower black shale unit is recognizable.

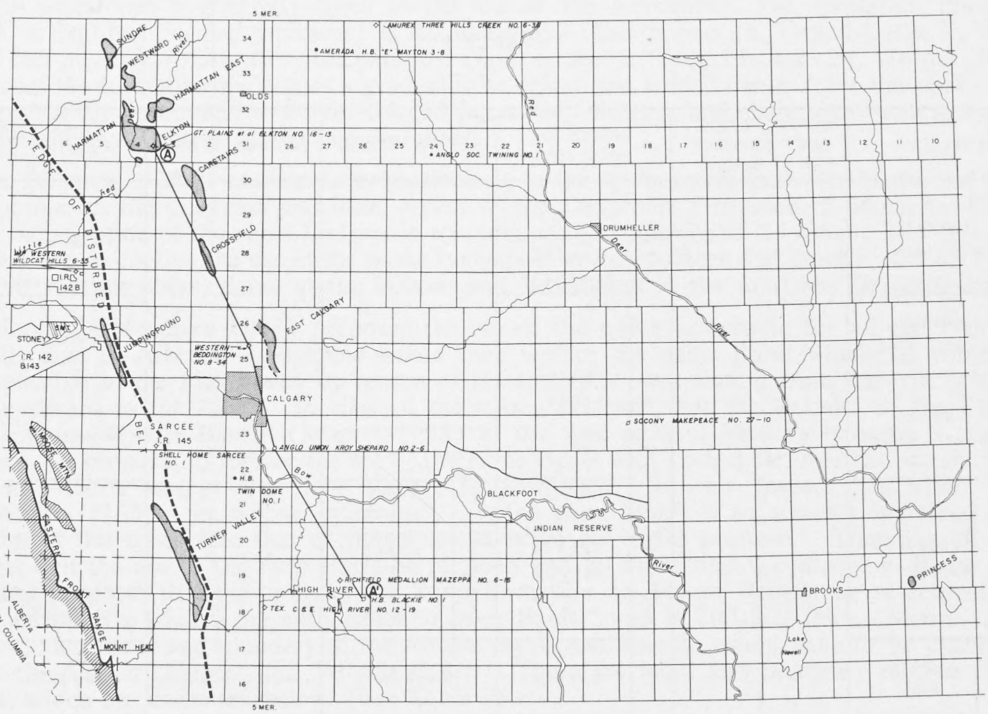
The Banff thins eastward and changes from a basinal facies in the Foothills to a shelf facies in the Plains. The Banff formation of the type section is not the Banff formation of the Plains. In order to be consistent with established Plains usage, it is proposed that the Banff formation and the Rundle group at the type section be re-defined.

The Elkton member of the Turner Valley is the most important oil and gas reservoir in the area. Accumulation occurs at the erosional up-dip edge of the Elkton, in stratigraphic traps controlled by facies changes, chanelling, and by the overlying impermeable Mesozoic shales.

Total recoverable reserves from the Turner Valley is 306,364,000 barrels of oil, — 88 percent of the total reserves of all producing zones in the area.

Introduction

The area covered by this paper is shown in Figure 1. The Mississippian thins from 2,840 feet in the west to its truncation edge in the northeastern corner of the map-area (Fig. 2) due largely to post-Palaeozoic erosion which bevelled the strata so that progressively older beds are exposed at the erosional surface in a northeasterly direction.



INDEX MAP OF CONFERENCE AREA
SHOWING MISSISSIPPIAN GAS AND OIL FIELDS
AND LINE OF CROSS SECTION

SCALE: 0 4 8 16 MILES

FIGURE 1

1 Consulting Geologist, Calgary, Alberta.

The writer gratefully acknowledges the assistance received, in the form of data, from several oil companies. Thanks are due R. E. Anderson and L. E. Workman, Canadian Stratigraphic Service Ltd., for making their lithological logs available.

The Mississippian sediments are disconformably underlain by Devonian rocks; they are unconformably overlain by Jurassic rocks in the western part and by Cretaceous rocks in the eastern part of the map-area.

Production of oil and gas is principally from the Turner Valley formation. The important oil fields are Turner Valley in the Foothills, and Sundre, Westward Ho, and Harmattan-Elkton in the Plains. In addition several gas pools have been discovered along the trends of these oil fields and are presently at various stages of development. These are Jumpingpound, Sarcee and Wildcat Hills in the Foothills, and Carstairs, Crossfield, and East Calgary in the Plains. The Pekisko formation is of secondary importance as a Mississippian reservoir. Oil was produced from the Pekisko at Princess until 1958, and there are a few gas and oil discoveries that have not been developed to date. The remaining formations, Bakken, Banff, Shunda and Mount Head are not productive, but some have given encouraging shows of gas and oil.

Stratigraphy

For a detailed description of the subdivision, nomenclature, and lithology of the Mississippian rocks of southern Alberta, the reader is referred to the symposium "Jurassic and Carboniferous of Western Canada" (1958). The particularly pertinent papers in this volume are by Moore, Douglas and Harker, and Penner. Other papers relative to particular stratigraphic intervals or areas will be mentioned in the summary of the stratigraphy that follows.

The Mississippian of south-central Alberta is divided into six formations. These are, in ascending order: Bakken, Banff, Pekisko, Shunda, Turner Valley and Mount Head. The Turner Valley formation is sub-divided into the Elkton, Middle Dense, and Upper Porous members (Table I).

Table I

BOW VALLEY	PROPOSED RUNDLE / BANFF BOUNDARY ON MT. RUNDLE	JASPER TO MOOSE MTN.	WESTERN PLAINS	EASTERN PLAINS	FAUNAL ZONE HARKER - RAASCH (1958)
RUNDLE GROUP: TUNNEL MOUNTAIN	RUNDLE	RUNDLE GROUP: TUNNEL MOUNTAIN			Spirifer leidyi Spirifer increbescens
RUNDLE GROUP: UPPER MOUNT HEAD	RUNDLE	RUNDLE GROUP: MOUNT HEAD			Faberophyllum
RUNDLE GROUP: LOWER MOUNT HEAD	RUNDLE	RUNDLE GROUP: MOUNT HEAD	MOUNT HEAD		Ekvasophyllum
RUNDLE GROUP: TURNER VALLEY	RUNDLE	RUNDLE GROUP: TURNER VALLEY	TURNER VALLEY: UPPER POROUS MIDDLE DENSE		Spirifer keokuk
RUNDLE GROUP: TURNER VALLEY	RUNDLE	RUNDLE GROUP: TURNER VALLEY	TURNER VALLEY: ELKTON		Spirifer forbesi
BANFF: UPPER BANFF	RUNDLE	RUNDLE GROUP: SHUNDA	SHUNDA	SHUNDA	Spirifer rowleyi
BANFF: MIDDLE BANFF	RUNDLE	RUNDLE GROUP: PEKISKO	PEKISKO	PEKISKO	Camarotoechia cobblestonensis
BANFF: LOWER BANFF	BANFF	BANFF	BANFF	BANFF	Spirifer missourienensis Spirifer marionensis
EXSHAW	EXSHAW	EXSHAW	EXSHAW SHALE	BAKKEN	Goniatite

BAKKEN FORMATION

The typical Bakken formation of the Dakotas, Montana, and Saskatchewan is present in the eastern part of the map-area (Fig. 1). Here the Bakken is divided into four lithological units. The two black shale units at the base and top of the formation are easily indentified on Gamma Ray logs by their highly radioactive character; the medial sand, which underlies the upper black shale unit, has been named Coleville sand after the Coleville field in Saskatchewan. (Twp. 31, Rge. 23, W3M.), where it is the principal oil reservoir. The fourth unit is a characteristic dolomitic siltstone that commonly overlies the basal black shale unit.

In the area of typical Bakken deposition (referred to above) the formation reaches a thickness of 150 feet, but the average thickness is approximately 100 feet. Northward and toward the north-central part of the map-area, the upper part of the formation thins and changes facies to shale that is indistinguishable from the overlying Banff shale; only the lower black shale unit of the Bakken formation, described earlier, is recognizable. Westward the formation is again represented by one identifiable thin, black shale bed, which marks the base of the Mississippian System. The writer, in an earlier paper (1958), interpreted the thinning of the Bakken to the west as indicative of the depositional edge of the formation. No new evidence to support or refute this interpretation has been brought forward.

BANFF FORMATION

In the Foothills the Banff formation consists of a dark-colored, argillaceous limestone and calcareous shale sequence that overlies the black shale of the Bakken, and underlies the massive, coarse-crinoidal limestone of the Pekisko. Dark-colored chert is common. The contact with the overlying Pekisko is gradational, which results in conflicting formation picks. The first appearance of dark grey, calcareous shale, or dark, argillaceous limestone, beneath the Pekisko crinoidal limestones is generally taken as the top of the formation. The formation thins eastward from 750 feet (drilled thickness) at Roxana No. 1 (Lsd. 5, Sec. 18, Twp. 24, Rge. 7, W5M.) to 575 feet at Anglo-Union-Kroy Shepard 2-6 (Lsd. 6, Sec. 2, Twp. 23, Rge. 29, W4M.). Farther to the east the formation undergoes a gradual lithological and color change from the dark-colored rocks previously mentioned to lighter-colored limestone, siltstone, and shale, representing a change from basinal environment to shelf environment.

In the area of shelf environment, particularly in the southeastern part of Alberta, the formation approaches the thickness and lithic aspect of the Lodgepole formation of Montana. For this reason the adoption of the name Lodgepole was proposed by the writer (1958a). The thought at that time was to confine the use of the name Lodgepole to the southern and eastern parts of Alberta where its two members, Paine at the bottom and Woodhurst at the top, may be recognized.

Moore (Addendum, 1958) proposed the use of the name Lodgepole for all the Plains and Foothills area in Alberta. Lodgepole would then replace the name Banff which, he contends is not applicable in the Plains area by reason of his concept of correlation from the type section at Banff eastward to the Plains. In view of the strong evidence that the Pekisko of the Plains is equivalent to "Middle Banff" (Moore, 1958) at the type section, Moore's concept is accepted. However, his proposal to replace the use of the name Banff with Lodgepole, in what amounts to all areas in Alberta except the Bow Valley, is questioned. In this respect the writer agrees with Austin (1958) in whose opinion ". . . the name Banff is so strongly ingrained in the literature of the subsurface that a change would serve no useful purpose." Therefore, it seems practical that the use of the term Banff be retained and, in order that it conform to Plains usage, the writer proposes that the limits of the Banff formation on Mount Rundle be re-defined. The re-defined Banff is what is presently called "Lower Banff," and is 700 feet thick (Moore, 1958). It follows that the lower boundary of the Rundle on Mount Rundle would have to be extended to include the present "Upper" and "Middle Banff." There are valid and necessary reasons for this revision which are discussed below. (See Table I).

PEKISKO FORMATION

The Pekisko formation consists predominantly of light-colored, coarsely crinoidal, fragmental, and fine-grained, sparsely crinoidal limestone. In the general Calgary region the thickness of the Pekisko is 300 feet except in local areas where it thickens at the expense of the underlying Banff formation. The apparent thinning of the Pekisko to 200 feet towards the northwest part of the map-area was earlier thought to be due to a facies change but, with the control now available, a sedimentary thinning and final pinch-out of the upper Pekisko beds northwest from the Calgary region can be demonstrated.

Faunally, the Pekisko formation carries what Harker and Raasch (1958) designate as the *Camarotoechia cobblestonensis* zone. They state "The fauna occurs in that portion of the lower Rundle that underlies the Shunda formation, from the Jasper area south through the front ranges and the foothills at least as far as Moose Mountain. At Banff, it is present in what appears to be Warren's "Middle Banff," in a horizon which Beales (1950) shows to lie more than 800 feet above the Exshaw shale. In the plains subsurface, Raasch identified the fauna from cores in the Granum area."

"At Lake Minnewanka, Crickmay's (1955) beds 27 to 33, which he indicates to correspond to Shimer's (1926) beds 22 to 31, appear to fall within the time interval of the *C. cobblestonensis* zone and the Pekisko formation."

These authors are quoted at length to show the great areal extent of the *C. cobblestonensis* fauna and its association with the Pekisko formation. The reader's attention is drawn to the use of the name lower Rundle for the Pekisko interval in the Jasper area, and to its widespread faunal correlation with the "Middle Banff" at Banff and the Pekisko of the Plains. In terms of Moore's concept of correlation the name Rundle is used in a different sense in the quotation. However, in the past the base of the Rundle has been placed at the base of the Pekisko in all areas except at the type section on Mount Rundle. This would appear to lend support to the argument for extending the definition of the term Rundle at its type section to include the "Upper" and "Middle Banff."

SHUNDA FORMATION

The Shunda formation is a clastic-carbonate unit lying between two relatively clastic-free carbonate formations, the Pekisko below and the Turner Valley above. Penner (1958b) describes a cored section in the Westward Ho field that may be regarded as an alternate type section for south-central Alberta. In the subsurface, immediately west of the erosional edge of the Turner Valley formation, the Shunda is approximately 150 feet thick and consists of cryptocrystalline, silty dolomite, dolomitic siltstone, sandstone, and green shale; breccias are characteristic of the formation. Westward from this trend the lithology and thickness of the Shunda changes. At Home-Shell Priddis 10-19 (Lsd. 10, Sec. 19, Twp. 22, Rge. 3, W5M.) anhydrite and red beds replace the equivalent silty dolomite beds of the eastern area, indicating restricted lagoonal conditions and very shallow water.

Further westward there is a notable facies change at the top of the formation to brown lithographic limestone indicative of deeper water and a marine environment. This characteristic limestone is the so-called "Black Lime" of the Turner Valley field and the eastern part of the Foothills.

In the western part of the Foothills, information on the Shunda is confined to one well, Roxana No. 1 (Lsd. 5, Sec. 18, Twp. 24, Rge. 7, W5M.), and the outcrops in the Moose Dome and Mount Head areas. At Roxana No. 1 the Shunda formation is similar in lithology and thickness to that of the Turner Valley field. The surface exposure of the Mississippian at Moose Dome (Twp. 23, Reg. 6, W5M.) is described by Beach (1943) and the approximately portion of the description that the writer interprets as the Shunda read as follows:

Very fine-grained, brittle dolomite. Weathers into thin plates with sharp, hackly edges. Small calcite-filled vugs common and also many poorly preserved fossil fragments	243 feet
Buff weathering, fine-grained, dark brown dolomite	20 feet

Beach's thickness is in excess of the thickness measured by Illing (personal communication) by 73 feet and exceeds the thickness of the Shunda at other locations.

The regional correlation westward from the Roxana well to the Mississippian outcrops of the Mountains and the type section of the Mississippian on Mount Rundle is the subject of an Addendum to Moore's (1958) paper. Moore contends that the Shunda of the Plains is equivalent in age to the "Upper Banff" at Banff. In view of the evidence that the "Middle Banff" at Banff is equivalent to the Pekisko of the Plains, Moore's correlation is substantiated.

TURNER VALLEY FORMATION

The Turner Valley formation conformably overlies the Shunda formation. The formation, 350 to 400 feet thick, consists of bioclastic carbonates in the form of coarse-crinoidal, and fine-crystalline, bryozoan-bearing limestone or dolomite; and interbedded, dense, hard, slightly silty and cherty dolomite. The latter occurs in the middle of the formation and is the basis for subdividing the formation into three members. These are, in ascending order Elkton, Middle Dense, and Upper Porous.

ELKTON MEMBER

This member was originally named, defined and described by Penner (1958a) in a paper that was submitted for publication in 1957. Later the member was the subject of another paper by Penner (1957) in which the Elkton was subdivided into three sub-members. The upper and lower sub-members consist of porous carbonates and are designated "A" and "B" respectively. They are separated by a middle sub-member two to ten feet thick, consisting of green, dolomitic shale or argillaceous and silty dolomite, impregnated with finely disseminated pyrite and pyrite pellets.

The two porous sub-members "A" and "B" are productive of gas and oil at or near the eastern erosional limit of the Elkton member. The "A" sub-member consists of fine-crystalline, sucrosic dolomite which may have chert inclusions. The "B" sub-member consists, for the most part, of dolomite which is subject to a facies change to limestone that is impervious and unproductive. The known occurrences of limestone in the sub-member are shown in Figure 4.

The correlation of the three sub-members of the Elkton along the erosional edge is shown in Figure 3. A pronounced thickening of the member southeastward from the type section at Great Plains et al Elkton 16-13 is indicated (line of Section Fig. 1).

The writer's correlation westward from the type section to Shell Anglo Pine Creek No. 1 (Lsd. 12, Sec. 12, Twp. 20, Rge. 2, W5M.) and the Turner Valley field section has been published in the two papers mentioned above. Since these papers have been published a few geologists have expressed their opinions in regard to the correlation of the Elkton member westward. In brief, these geologists equate only the sub-member "B" to the interval 9,195 to 9,340 feet in Shell-Anglo Pine Creek No. 1, and to the combined "Lower Porous" and "Crystalline Zone" of the Turner Valley field terminology, on the basis that these units are predominantly coarse-grained rock at these locations. The "A" sub-member is considered to be a porous dolomite development of the basal part of the Middle Dense in the area flanking the erosional limit of the Elkton member.

While this argument seems logical it may also be questioned when it is considered that the "A" sub-member changes facies from the fine-grained rock in the Elkton area to coarse-grained crinoidal limestone or dolomite in regions south of the map-area. On a regional basis, therefore, the top of possible bioclastic development appears to be near the top of the "A" sub-member rather than at the top of the "B" sub-member as in the area near the erosional limit. Inasmuch as the Elkton member was named and defined in that sense it is regarded by the writer as a recognizable and useful rock unit, particularly from the economic point of view.

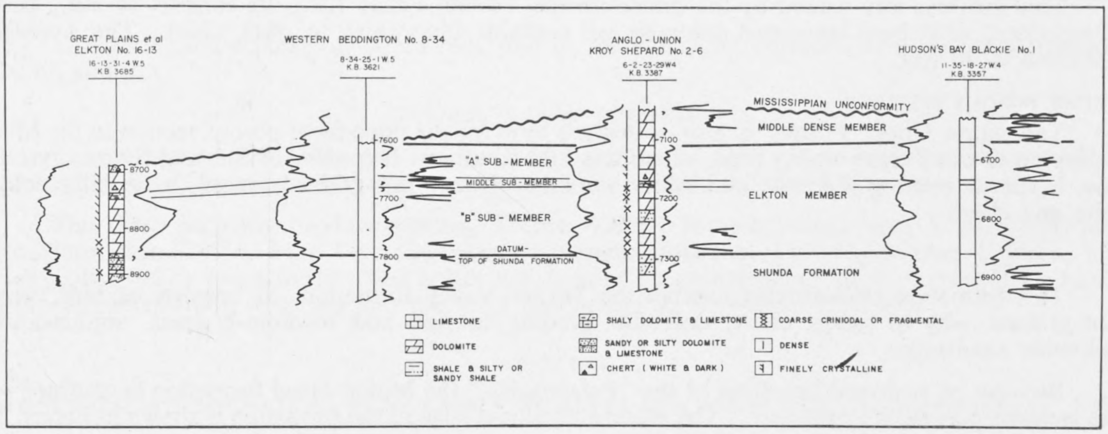
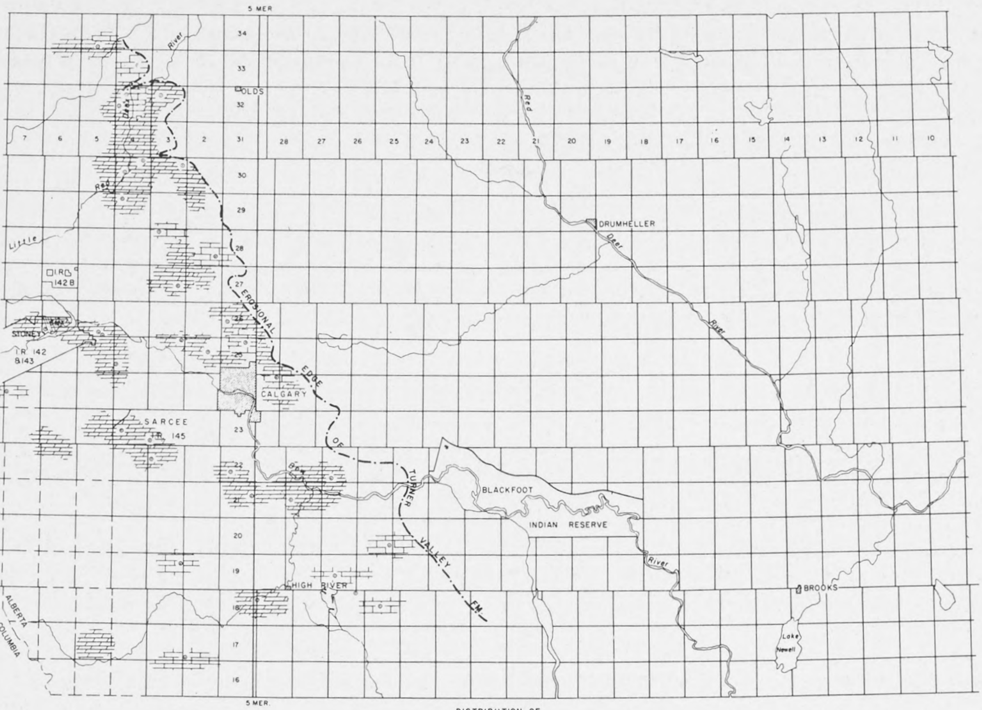


FIGURE 3

Stratigraphic correlations of sub-members of Elkton from Great Plains et al Elkton 16-13 south-eastward to Hudson's Bay Blackie No. 1.



DISTRIBUTION OF
DOLOMITE AND LIMESTONE FACIES
OF
'B' SUB-MEMBER, ELKTON MEMBER

FIGURE 4

MIDDLE DENSE MEMBER

This member was named by the drillers in the Turner Valley field. It consists of buff, very fine-grained, silty, hard laminated dolomite and contains blue-white to dark chert. The average thickness is 90 feet.

UPPER POROUS MEMBER

The name Upper Porous is also a driller's term for the uppermost porous section in the Mississippian of the Turner Valley field, where it is 100 feet thick. It consists of fine and coarse-crystalline, bryozoan-bearing dolomite and minor amounts of very fine-grained, dense, hard, silty dolomite and chert.

MOUNT HEAD FORMATION

This formation conformably overlies the Turner Valley formation. It consists of buff, very fine-grained, silty to sandy, cherty dolomite, grading to fine and medium-grained, argillaceous, dolomitic sandstone.

Because of eastward bevelling of the "Palaeozoics," the Mount Head formation is confined to the western part of the map-area. The eastern erosional edge of the formation is shown in Figure 2.

ECONOMIC CONSIDERATIONS

Within the map-area the Mississippian rocks contain the major gas and oil accumulations of the Foothills and Plains. Production is at present primarily from the Turner Valley formation, however, the Pekisko formation has produced some oil in the past. The Bakken, Banff, Shunda, and Mount Head formations are not productive but some have had small oil or gas showings that deserve comment. The overall economic considerations of the Mississippian within this area are treated under the formation headings in ascending order.

BAKKEN FORMATION

In the area of typical Bakken deposition in Alberta, the Coleville sand, is well developed and its potentiality as a possible reservoir has been recognized since the beginning of the search for gas and oil in Alberta. Encouraging oil staining has been encountered at many locations within the map-area, but drillstem test results to date have indicated either water or an absence of necessary porosity and permeability in this formation. This sand should not be condemned as a possible oil and gas horizon in spite of its poor performance to date.

BANFF FORMATION

The lithology of the Banff is such that it is generally not regarded as prospective for oil and gas. Some tests which have, however, been run at a few locations indicate encouraging oil and gas shows. These are confined to the upper half of the formation where there exists the possibility of encountering local developments of clean crinoidal beds.

PEKISKO FORMATION

Oil has been produced from the Pekisko at the small South Princess oil field in Township 19, Range 11, W4M. The field, situated at the up-dip erosional edge of the Pekisko was discovered in 1946, and until its abandonment in 1958, had produced 476,566 barrels of medium gravity oil and 948,838 Mcf gas. The reservoir is associated with the erosional unconformity.

Although the South Princess field is the only Pekisko reservoir with any appreciable areal extent, there are a number of wells drilled within the sub-crop area of the Pekisko that had good showings of light gravity oil, but upon development, were proved to be of local extent. The more important wells are Socony-C.P.R. Makepeace 27-10 (Lsd. 10, Sec. 27, Twp. 23, Rge. 19, W4M.) and Anglo-Socony Twinning No. 1 (Lsd. 8, Sec. 9, Twp. 31, Rge. 24, W4M.). More recently, in the general Wimborne area, a substantial amount of gas was discovered in the Pekisko formation at Amurex-Murphy Three Hills Creek 6-36 (Lsd. 6, Sec. 36, Twp. 34, Rge. 26, W4M.) and oil at Amerada-H.B. "A" Mayton (Lsd. 3, Sec. 8, Twp. 34, Rge. 27, W4M.). See Figure 1.

The performance of the Pekisko has not been good to date, but its economic importance should not be underestimated. In the sub-crop area the resistive character of the Pekisko has resulted in substantial relief in the form of ridges, pronounced salients, and deep valleys, giving rise to structural highs and lows in the overlying Cretaceous strata. The erosional features are well illustrated in Figure 2.

SHUNDA FORMATION

This formation consists of dense rock and is, therefore, not regarded as a potential reservoir for oil and gas.

TURNER VALLEY FORMATION

This formation has accounted for the major portion of total oil and gas production within the map-area. The two productive members are the Elkton and the Upper Porous.

The three currently producing areas, Turner Valley, Jumpingpound, and Sundre-Westward Ho-Marmattan-Elkton, have been described in detail by Gallup (1951), Martin (1956), and Hemphill (1957) respectively. The writer will confine his comments on each of these fields to the estimated recoverable reserves and the total production to December 31, 1958.

TABLE II

TURNER VALLEY FORMATION, RECOVERABLE RESERVES AND PRODUCTION TO DECEMBER 31, 1958

Field	Recoverable Reserves (A)		Production to Dec. 31, 1958 (B)	
	Oil (MM of Barrels)	Gas (BCF)	Oil (Barrels)	Gas (MMCF)
Turner Valley	196.448		114,759,938	1,763.584
Jumpingpound		577	961,805	114.076
Sundre-W.H., H.-E.	109.916		4,359,712	6.705

Sources of data (A) Petroleum Digests, Mr. S. Brodylo, Calgary
(B) Oil and Gas Conservation Board, Calgary.

The total recoverable reserves from the Turner Valley formation, 306,364,000 barrels, is 88 percent of total reserves from all zones. This is followed by 9.5 percent from the Devonian and 2.5 percent from the Cretaceous.

In addition to the producing fields mentioned above, there are several gas discoveries along the established trends of these fields. Recently an important gas discovery in the Turner Valley formation was made at Imperial-Western Wildcat Hills 6-35-27-6 (Lsd. 6, Sec. 35, Twp. 27, Rge. 6, W5M.).

In the Plains and along the Sundre-Westward Ho-Harmattan-Elkton trend there are three commercial gas fields, at various stages of development (Fig. 1). These are: Carstairs (5 wells), Crossfield (3 wells), and East Calgary (3 wells). All these fields are at the eastern erosional edge of the Elkton member and this feature, together with the ideal cap provided by the overlying Jurassic or Cretaceous shale provides some of the necessary trap conditions. Two other important factors that account for the accumulations are the variable distribution of the limestone facies in the "B" sub-member (Fig. 4), and the deep channels cutting across the erosional limit (Fig. 2). Whereas the first two factors prevented the oil from moving eastward and up-dip, we may regard the last two as playing an equally important part in preventing southeasterly hydrocarbon migration.

In the Plains south of the fields mentioned above, there are three significant undeveloped gas and oil discovery wells from the Turner Valley formation. These wells, Texaco - C. and E. High River 12-19 (Lsd. 12, Sec. 19, Twp. 18, Rge. 29, W4M.), Richfield-Medallion Mazeppa 6-16 (Lsd. 6, Sec. 16, Twp. 19, Rge. 27, W4M.), and Hudson Bay Twin Dome No. 1 (Lsd. 16, Sec. 8, Twp. 22, Rge. 1, W5M.) are a considerable distance down-dip from the erosional edge, and this indicates that production from the Turner Valley formation in the Plains is not restricted to its erosional edge. See Figure 1.

MOUNT HEAD FORMATION

The Mount Head formation has not been proven productive to date due to the absence of porosity. However, the existence of a local area where this condition is satisfied is a good possibility.

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FACIES AND POROSITY RELATIONSHIPS IN THE MISSISSIPPIAN ELKTON CARBONATE CYCLE OF SOUTHWESTERN ALBERTA

G. E. THOMAS and R. P. GLAISTER [1]

Abstract

Major hydrocarbon (oil and gas) reserves have been found in the Mississippian Elkton carbonate cycle, both in the Foothills belt and along the subcrop, in southwestern Alberta. Effective reservoir material of this cycle was found to consist mainly of the dolomitized equivalent of an originally coarse skeletal limestone with a variable amount of generally porous, finely comminuted (granular) skeletal matrix. Primary porosity was very important in the control of dolomitization, which probably began with the replacement of this matrix by euhedral rhombohedrons and finally affected the coarse skeletal material (now generally indicated by leached fossil cast outlines). These porous dolomites grade laterally in a predictable way into tight, relatively undolomitized, well-sorted, coarse skeletal limestones with original high interfragmental porosity now completely infilled with clear crystalline calcite. This lithification by cementation took place early in the history of carbonate sedimentation of this area and before secondary dolomitization processes took effect.

Introduction

During the past ten years there has been an increasing demand from industry, national geological organizations and universities to organize the classification of carbonate rocks into a single, moderately detailed system of nomenclature which will be understood and used by all concerned. Unfortunately, it now appears that this demand will soon be met by not one but by a plethora of carbonate rock 'breakdowns.'

Any proposed carbonate rock classification which does not attempt to give an explanation for the variances in reservoir void space in limestone or dolomite sequences will not satisfy the requirements of an oil geologist or reservoir engineer. Effective porosity isopach and allied carbonate textural maps are essential to future exploration and exploitation programs in the Western Canada basin, because the bulk of hydrocarbons discovered to date are contained in carbonate stratigraphic traps of organic reef or clastic origin.

It is fortunate that carbonate sedimentation is so sensitive to environmental conditions that a wide variety of textures and structures result, each of which records the stamp of the depositional conditions which produced it. The full significance of carbonate rock textures in environmental interpretation and in evaluation of potential reservoir horizons is becoming more and more apparent.

In this paper some aspects of a textural and reservoir analysis of a Mississippian carbonate cycle are presented to illustrate the relationship that exists between the occurrence and petrographic nature of what constitutes an effective carbonate reservoir rock and the framework of carbonate sedimentation. Various types of carbonate rock pores, which are known to be characteristics of many limestone and dolomite sections, are described and evaluated with respect to effective porosity. These associations of textural type and porosity development are not found exclusively in one area. The descriptions here should be helpful in the recognition and mapping of such associations in other places.

Textural and Reservoir Properties of the Elkton Carbonate Cycle in Southwestern Alberta

Official nomenclature of well-defined Upper Mississippian (Rundle group), shelf carbonate cycles in southwestern Alberta is still burdened with old Turner Valley field names, such as 'Upper Porous' and 'Middle Dense' zones. Widespread transgressive sheets of coarse, generally dolomitized, fragmental (skeletal) limestones are separated by shallow water depositional units of silty, locally cherty, lithified carbonate muds which can be established as time stratigraphic boundaries for correlation purposes. However, it is not the purpose of this report to condemn present Mississippian nomenclature or to rename some of the carbonate cycles as has been done in southeastern Saskatchewan.

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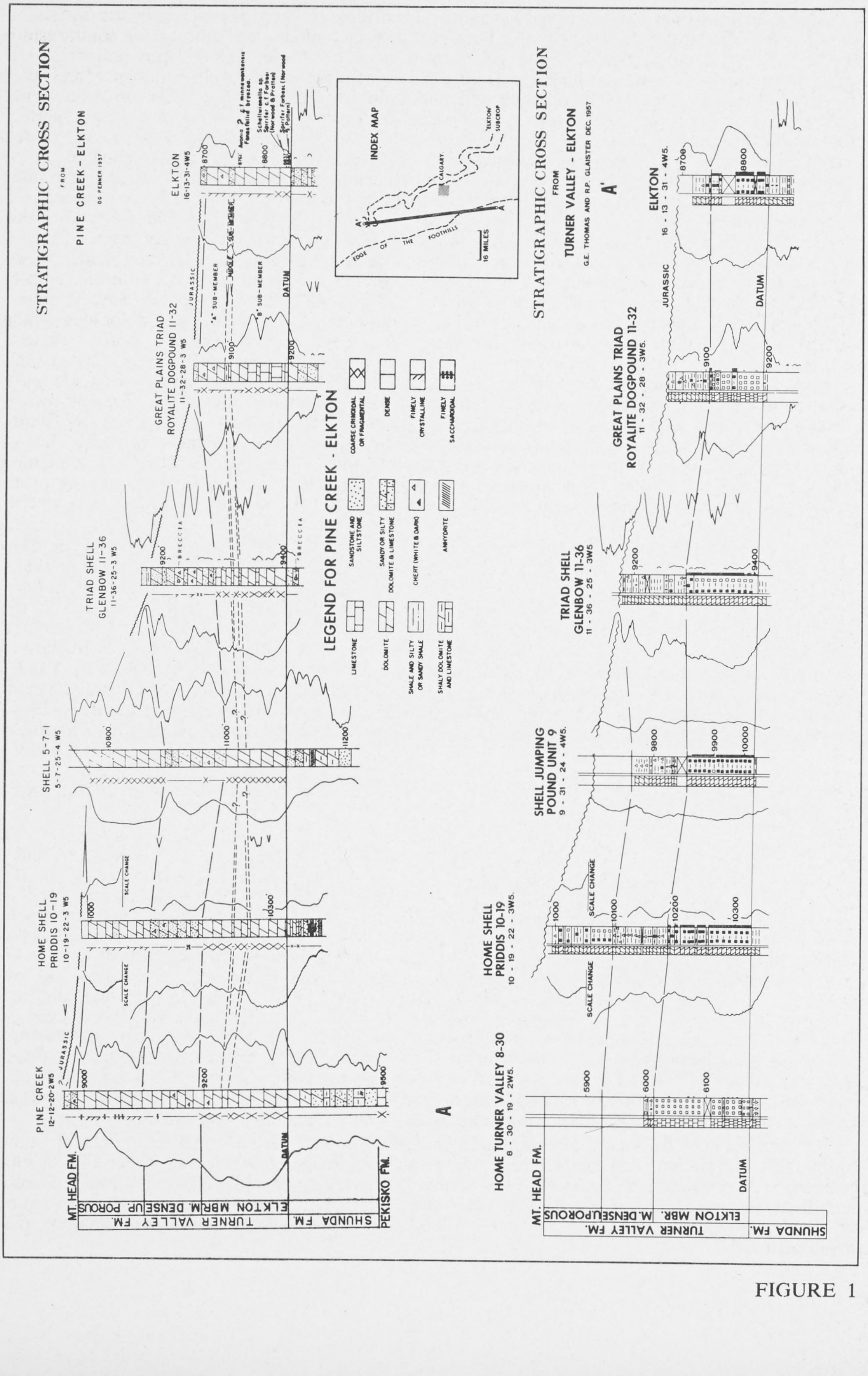
1 Geologists with Imperial Oil Limited. Thanks are due to Imperial Oil Limited for permission to publish this paper, which is a portion of a forthcoming publication entitled "Facies and Porosity Relationships in Some Mississippian Cycles of the Western Canada Basin."



STRATIGRAPHIC CROSS SECTION
FROM
PINE CREEK - ELKTON
D.G. PENNER 1957
LEGEND FOR PINE CREEK - ELKTON
INDEX MAP
STRATIGRAPHIC CROSS SECTION
FROM
TURNER VALLEY - ELKTON
G.E. THOMAS AND R.P. GLAISTER DEC. 1957

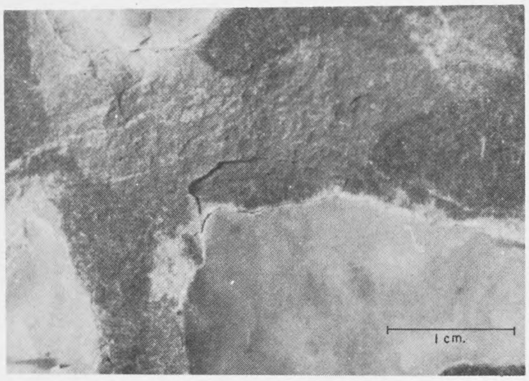
FIGURE 1

Major hydrocarbon (oil and gas) reserves have already been discovered in the Mississippian Elkton carbonate cycle, both in the Foothills belt and along the subcrop in southwestern Alberta. The Elkton carbonate cycle generally consists of coarse skeletal (predominantly crinoidal) carbonates, ranging in thickness from 80 to 150 feet with variable porosity and permeability. These carbonates are overlain and underlain by tight, lithified, silty-carbonate mud deposits up to the subcrop area, where the eroded reservoir material is covered by generally impermeable Mesozoic shales and silty sandstones. Porosity and permeability properties of the producing intervals in the Sundre, Westward Ho and Harmattan-Elkton fields, situated at or near the Elkton subcrop, can be directly related to quantitative, carbonate textural measurements. In this area, mechanical logs (neutron, micrology and microlaterolog) can be used to distinquish between effective and non-effective reservoir types. Effective reservoir material of this cycle was found to consist mainly of the dolomitized equivalent of an originally coarse skeletal limestone with a variable amount of porous, finely comminuted (granular) skeletal matrix. Primary porosity was very important in the control of dolomitization, which began with the replacement of this matrix by euhedral rhombohedrons and finally affected the coarse, skeletal material (now generally indicated by leached, fossil cast outlines). These porous dolomites grade laterally in a predictable way into tight, relatively undolomitized, well-sorted, coarse skeletal limestones, with original high interfragmental porosity now completely infilled with clear crystalline calcite. This lithification by cementation took place early in the history of carbonate sedimentation of this area and before secondary dolomitization processes took effect. Present hydrocarbon accumulation along the subcrop is controlled largely by up-dip truncation of the Elkton member. However, it is also strongly influenced by primary porosity pinchouts caused by lateral facies changes from dolomitized, leached, skeletal limestones with matrix, into tight, cemented skeletal limestones. Similar facies changes exist in the Turner Valley oil field, suggesting primary hydrocarbon accumulation in the Elkton member before Laramide structural movements took place.

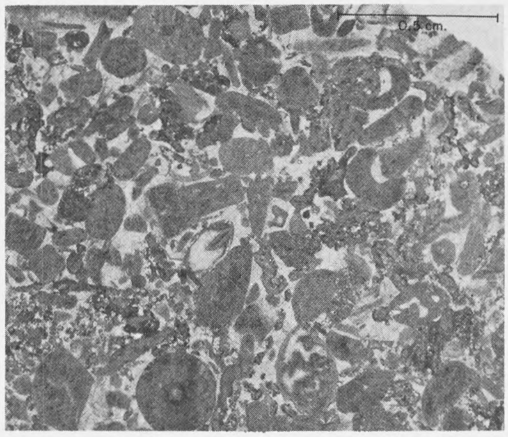
At the Jasper Conference of the American Association of Petroleum Geologists in September, 1955, D. G. Penner introduced the name Elkton member for the lower bioclastic or skeletal-rich unit of the Turner Valley formation. The proposed nomenclature was further refined by Penner (1957). The type section of this member was designated as that penetrated in the Great Plains et al Elkton 16-13 well (Lsd. 16, Sec. 13, Twp. 31, Rge. 4, W5M.) between the depths of 8,705 feet and 8,845 feet. Development drilling in the Harmattan-Elkton field showed that it was possible to subdivide the Elkton member into three sub-members (Penner, 1957). The Elkton member, 140 feet thick, was equated to the combined 'Lower Porous' and Crystalline Zone' of the Turner Valley field. Penner's published cross-section from Elkton 16-13 to the Pine Creek No. 1 (Lsd. 12, Sec. 12, Twp. 20, Rge. 2, W5M.) and intervening locations is shown in the upper half of Figure 1. While commending Penner's clarification of the relationship of the Sundre-Harmattan producing intervals to those of the Turner Valley oilfield, for regional correlation purposes, the authors have had to re-define the upper limits of his Elkton member (Fig. 1, lower half).

The "A" sub-member in the Harmattan-Elkton field was found to consist generally of a microcrystalline dolomite with scattered relict skeletal material and abundant inclusions of milky white chert. Rock photograph of Plate I.A is typical of this sub-member and shows it to be the dolomitized equivalent of washes of micro-to finely comminuted, skeletal material deposited in a lime-mud environment. Chert nodules, quartz-silt partings, and scattered plant fragment traces are common, suggesting muddy, shallow-water deposition which was unfavorable for much skeletal carbonate or good reservoir development. Microcrystalline (anhedral to subhedral) calcareous dolomites are generally the rule, with fairly high porosity (frequently over 10 percent) and low permeability. These dolomites quite often give rise to substantial blows of gas on drillstem test. Locally within the field, the "A" sub-member has good porosity and permeability, due to an increase in the amount of coarser textured, more rhombic dolomite of which the intercrystalline porosity has been supplemented by the presence of scattered, leached, coarse skeletal material. Within and away from the Harmattan-Elkton field these coarser-textured, rhombic dolomites with effective porosity grade laterally and vertically into cherty, silty, and argillaceous, microcrystalline dolomites that are texturally indistinquishable from Penner's middle sub-member.

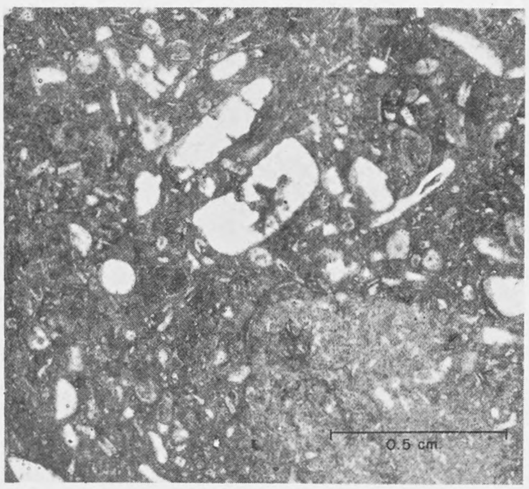
On the basis of carbonate texture, chert and silt content, depositional environment, time stratigraphic correlation, and general reservoir properties, Penner's middle and upper Elkton sub-members are considered to be lateral equivalents of the cherty, 'Middle Hard' or 'Middle Dense' zone of the Turner Valley oil field. For convenience the authors have designated Penner's lower sub-member, or main prospective zone, as the Elkton carbonate cycle, which will now be discussed in detail.



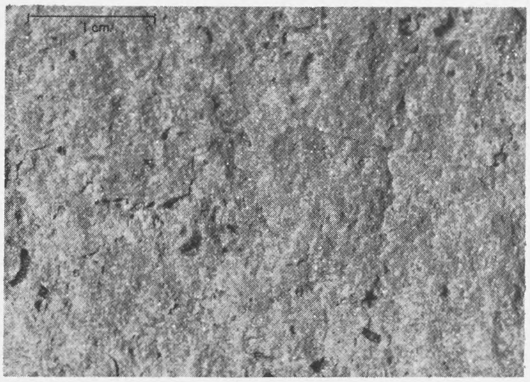
(A)
Cherty microcrystalline
dolomite
Horizontal core



(B)
Cemented skeletal (crinoid-
bryozoa) limestone
Thin section



(C)
Dolomitized leached skeletal
limestone with porous matrix
Thin section



(D)
Microrhombic dolomite with
leached fossil casts
Horizontal core

PLATE I

For mapping purposes, the Elkton carbonates can be broken down into effective and non-effective porosity units.

ELKTON CARBONATES WITH NO EFFECTIVE POROSITY

CEMENTED SKELETAL AND NON-SKELETAL CARBONATES

Of great interest is the widespread occurrence in the Elkton cycle of thick deposits of generally coarse, cemented skeletal limestones ('crystalline' limestones of former workers). These are composed predominantly of the calcareous remains of disarticulated echinoderm ossicles and plates. Although space between crinoid fragments in rocks of this type consists largely of clear crystalline calcite, few samples lack at least some organic remains of non-crinoidal origin. Most commonly the 'foreign' material consists of bryozoan fragments. These tight, coarse, skeletal limestones, with high original interfragmental porosity, now completely infilled with clear crystalline calcite, usually analyze less than 5 percent porosity and 0.1 millidarcies permeability. Apparently, earlier workers did not recognize echinoderm plates and ossicles as rock builders in the lower 'Crystalline Zone' of the Turner Valley oil field and referred to them as calcite crystals. Even in recent excellent papers such as the one by C. R. Hemphill (1957), such statements as "in the No. 9-22 well the section consisted of limestone, medium-grey, medium to coarsely crystalline, and slightly fossiliferous" are to be found.

The thin section photograph (Pl.I.B) should clarify concepts as to what constitutes a 'crystalline' or cemented skeletal limestone. Even though cemented skeletal or non-skeletal limestones are found from the Cambrian to Quaternary and contribute to most carbonate text-book photographs, very few authors have committed themselves in mode of origin discussions. The clear-crystalline calcite cement of the sorted skeletal or non-skeletal limestones might be interpreted as reorganized lime-mud matrix or as primary calcite cement. The authors concur with R. C. Moore's observations on the Mississippian of the Ozarks and believe it to be a primary chemical precipitate for the following reasons:—

(a) The crystalline cement is present in considerable amounts only in skeletal or non-skeletal limestones that have a relatively high degree of sorting and rounding. This suggests that much of the interstitial fine material was winnowed out by strong currents or shoaling water where wave action was effective. This winnowing process would create interstitial voids favorable for the formation of primary crystalline cement.

(b) Prominent crystalline calcite overgrowths on many grains, especially on crinoid columnals, are in optical continuity. Accordingly to Pettijohn, this continuity is a characteristic of primary cement.

(c) There are no relict structures of grains or comminuted fossils in the crystalline cement as would be expected if the cement was the product of a reorganized or replaced matrix. The cement was probably introduced into open pores in the course of diagenesis, being precipitated as crystal growths derived from carbonate saturated ground waters.

(d) Edges of the fossils or non-skeletal material are not corroded or altered in a manner suggesting effects of recrystallization.

This lithification by cementation took place early in the carbonate sedimentation history of this area, and before secondary dolomitization processes took effect. The very nature of the clear crystalline calcite cement infilling of primary interfragmental porosity inhibited dolomitization. Dolomitization of these limestones could develop along cleavage cracks in the calcite cement or along incipient fractures. Cemented skeletal or non-skeletal limestones in Devonian or Mississippian sections of the Rockies or Foothills belt, usually show effects of dolomitization processes as a result of stresses induced by mountain building.

Oolitic and associated surficially coated grains occur locally in cemented skeletal limestones of the Elkton member. Localities where these fringing shoal deposits have been found include the centre portion of the Turner Valley oil field, and the Blackie, Brant, Dogpound, and Sundre areas. For mapping purposes, these generally cemented, well-sorted, oolitic limestones can be grouped with cemented skeletal limestones, with which they are closely associated. Oolites are rare in unsorted skeletal limestones.

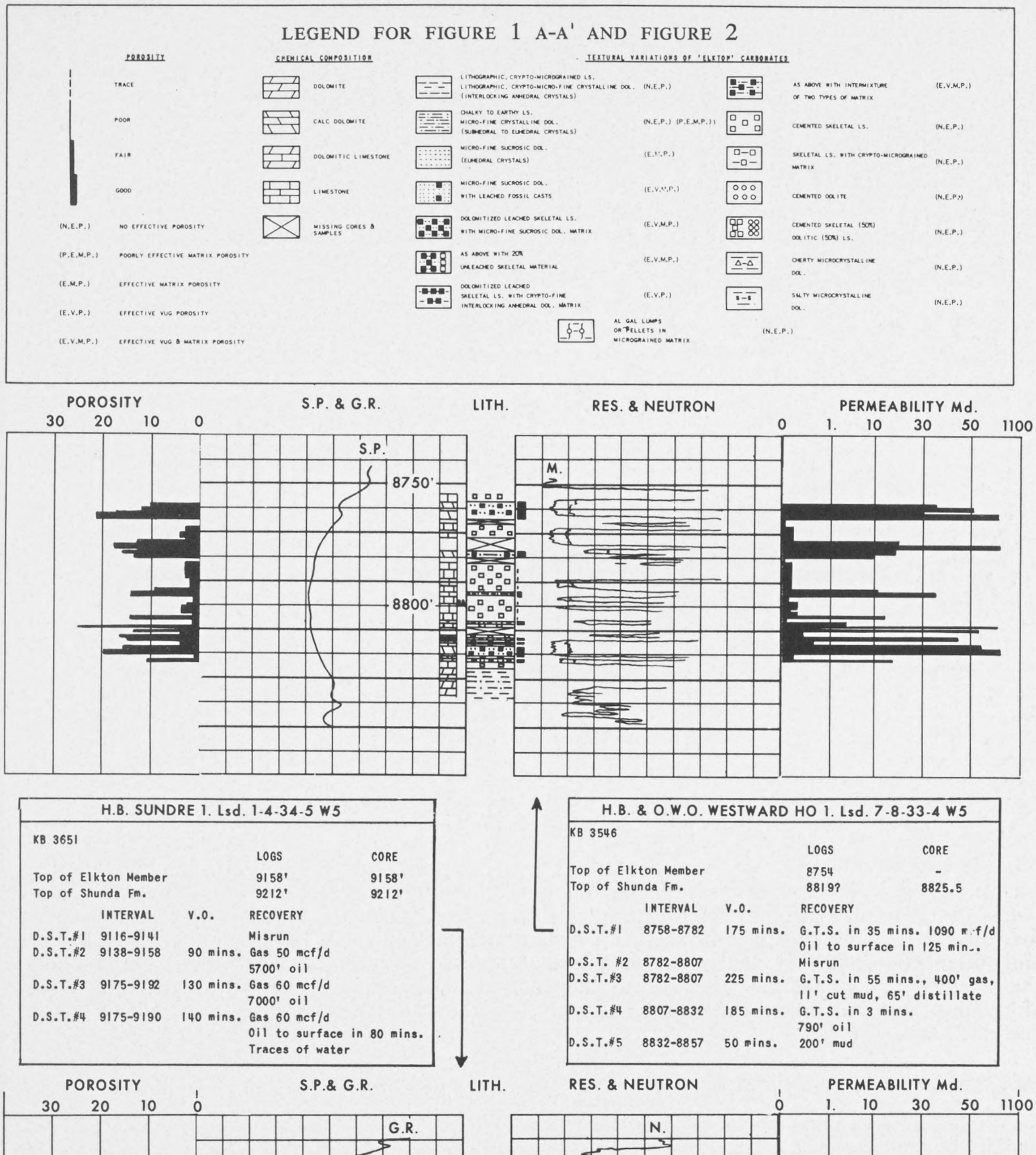

LEGEND FOR FIGURE 1 A-A' AND FIGURE 2
POROSITY
TRACE
POOR
FAIR
GOOD
(N.E.P.) NO EFFECTIVE POROSITY
(P.E.M.P.) POORLY EFFECTIVE MATRIX POROSITY
(E.M.P.) EFFECTIVE MATRIX POROSITY
(E.V.P.) EFFECTIVE VUG POROSITY
(E.V.M.P.) EFFECTIVE VUG & MATRIX POROSITY
CHEMICAL COMPOSITION
DOLOMITE
CALC DOLOMITE
DOLOMITIC LIMESTONE
LIMESTONE
MISSING CORES & SAMPLES
TEXTURAL VARIATIONS OF 'ELKTON' CARBONATES
LITHOGRAPHIC, CRYPTO-MICROGRAINED LS. LITHOGRAPHIC, CRYPTO-MICRO-FINE CRYSTALLINE DOL. (INTERLOCKING ANHEDRAL CRYSTALS) (N.E.P.)
CHALKY TO EARTHY LS. MICRO-FINE CRYSTALLINE DOL. (SUBHEDRAL TO EUHEDRAL CRYSTALS) (N.E.P.) (P.E.M.P.)
MICRO-FINE SUCROSIC DOL. (EUHEDRAL CRYSTALS) (E.M.P.)
MICRO-FINE SUCROSIC DOL. WITH LEACHED FOSSIL CASTS (E.V.M.P.)
DOLOMITIZED LEACHED SKELETAL LS. WITH MICRO-FINE SUCROSIC DOL. MATRIX (E.V.M.P.)
AS ABOVE WITH 20% UNLEACHED SKELETAL MATERIAL (E.V.M.P.)
DOLOMITIZED LEACHED SKELETAL LS. WITH CRYPTO-FINE INTERLOCKING ANHEDRAL DOL. MATRIX (E.V.P.)
ALGAL LUMPS OR PELLETS IN MICROGRAINED MATRIX (N.E.P.)
AS ABOVE WITH INTERMIXTURE OF TWO TYPES OF MATRIX (E.V.M.P.)
CEMENTED SKELETAL LS. (N.E.P.)
SKELETAL LS. WITH CRYPTO-MICROGRAINED MATRIX (N.E.P.)
CEMENTED OOLITE (N.E.P.)
CEMENTED SKELETAL (50%) OOLITIC (50%) LS. (N.E.P.)
CHERTY MICROCRYSTALLINE DOL. (N.E.P.)
SILTY MICROCRYSTALLINE DOL. (N.E.P.)
POROSITY
30 20 10 0
S.P. & G.R.
S.P.
8750'
8800'
LITH.
RES. & NEUTRON
M.
PERMEABILITY Md.
0 1. 10 30 50 1100
H.B. SUNDRE 1. Lsd. 1-4-34-5 W5
KB 3651
LOGS CORE
Top of Elkton Member 9158' 9158'
Top of Shunda Fm. 9212' 9212'
INTERVAL V.O. RECOVERY
D.S.T.#1 9116-9141 Misrun
D.S.T.#2 9138-9158 90 mins. Gas 50 mcf/d 5700' oil
D.S.T.#3 9175-9192 130 mins. Gas 60 mcf/d 7000' oil
D.S.T.#4 9175-9190 140 mins. Gas 60 mcf/d Oil to surface in 80 mins. Traces of water
H.B. & O.W.O. WESTWARD HO 1. Lsd. 7-8-33-4 W5
KB 3546
LOGS CORE
Top of Elkton Member 8754 -
Top of Shunda Fm. 8819? 8825.5
INTERVAL V.O. RECOVERY
D.S.T.#1 8758-8782 175 mins. G.T.S. in 35 mins. 1090 mcf/d Oil to surface in 125 mins.
D.S.T. #2 8782-8807 Misrun
D.S.T.#3 8782-8807 225 mins. G.T.S. in 55 mins., 400' gas, 11' cut mud, 65' distillate
D.S.T.#4 8807-8832 185 mins. G.T.S. in 3 mins. 790' oil
D.S.T.#5 8832-8857 50 mins. 200' mud
POROSITY
30 20 10 0
S.P.& G.R.
G.R.
9150'
9200'
LITH.
RES. & NEUTRON
N.
PERMEABILITY Md.
0 1. 10 30 50 1100

FIGURE 2

SKELETAL OR NON-SKELETAL LIMESTONES WITH CHALKY TO MICROGRAINED MATRIX

Of local interest are the skeletal or non-skeletal limestones containing a chalky matrix which are found in the Brant and Blackie areas, south of Calgary. Poor grain-sorting, presence of delicate bryozoan fronds, and chalky to micrograined matrix all suggest sheltered, quiet-water conditions of deposition. The chalky matrix material has high connate water content and virtually no oil saturation because of the fine capillary pores. These were the only areas where the microlog curve gave unreliable estimates of effective porosity in the Elkton reservoir.

DOLOMITIZED LIME MUDS AND UNLEACHED SKELETAL TO NON-SKELETAL CARBONATES WITH A TIGHT, ORIGINALLY LIME-MUD MATRIX

All gradations from original cryptograined limestone to relict skeletal or non-skeletal limestone with, for example 5 to 10 percent cryptograined matrix, can be seen. The lime mud was apparently easily dolomitized to produce a crypto-to microcrystalline, anhedral, interlocking type of dolomite with no effective porosity.

ELKTON CARBONATES WITH EFFECTIVE POROSITY

The only extensively developed reservoir rock in the Elkton member is dolomite. Investigations so far completed suggest that secondary dolomitization of skeletal and other limestones took place on a volume-for-volume relationship, and that the porosity of the resultant dolomite (apart from leaching effects) was inherited from the original limestone. The secondary dolomites are generally coarse grained, in many cases with relict limestone textures or casts of fossil debris. On the basis of relict textures in these dolomites, it is possible to carry the zonation of limestone textural types into predominantly dolomite sections.

With regard to the relationship of dolomite development to textural features of original limestones, it has been observed that it preferentially occurs in open pores or in matrix (chalky, granular, and lime-mud) material that surrounds the larger skeletal or non-skeletal grains. These larger grains are generally the last to show conversion to dolomite. Skeletal fragments in many cases remain as calcite even when the remainder of the rock may be all dolomite. The final type in this sequence is a dolomite with fossil casts. This preferential development of dolomite in certain textural components of the original limestone suggests that dolomitization processes are strongly controlled by the presence of fluids in interfragmental or intergranular porosity or by lime-mud material that had a high fluid content.

It is possible to designate the composition of the original matrix material through studies of the grain-size and shape of the resultant dolomite. An interlocking or anhedral type of crypto-microcrystalline dolomite matrix is interpreted as derived from lime mud. The comminuted or pulverized, generally porous, granular and chalky material, either of skeletal or non-skeletal origin, often contributes to matrix or intergranular porosity in carbonate reservoirs. On dolomitization, this porous material gives rise to subhedral or euhedral (rhombic) dolomites with intercrystalline porosity, unless the enlargement of the granules has continued too far to produce 'mosaic' textural types.

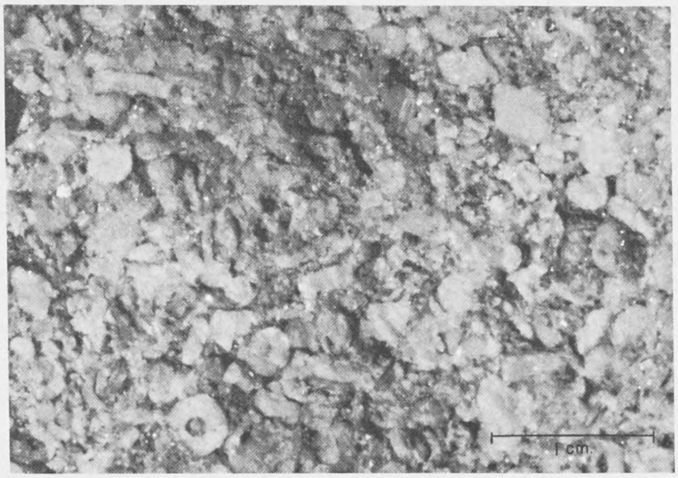
DOLOMITIZED LEACHED SKELETAL LIMESTONES WITH POROUS MATRIX

The most effective reservoir material of the Elkton carbonate cycle was found to consist mainly of the dolomitized equivalent of an originally coarse, skeletal limestone with a variable amount of generally porous, finely comminuted (granular) skeletal matrix. Primary porosity was very important in the control of dolomitization and much of the dolomite replacement occurred very shortly after the limestone was laid down. Dolomitization probably began with the replacement of the porous granular matrix by sub-euhedral rhomohedrons and finally affected the coarse, skeletal material (now generally indicated by leached fossil cast outlines). Highest permeabilities occur where fossil casts supplement the pore space between the packed dolomite rhombs (Pl.I.c). This permeability is proportionately reduced when relict unleached skeletal material remains in the rock.

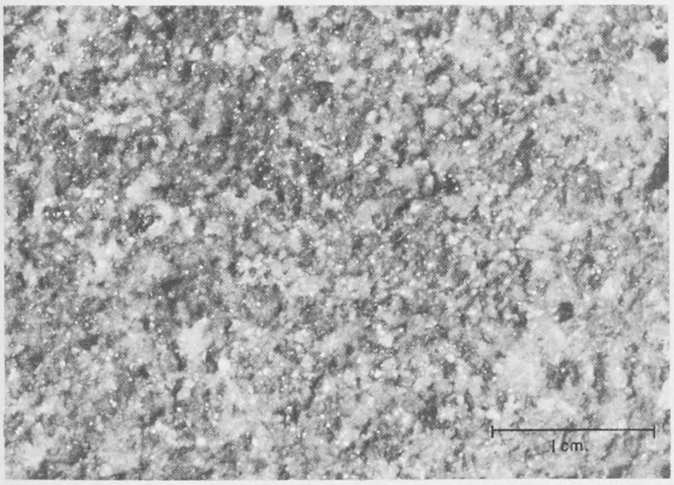
It is interesting to note that the highest porosities and permeabilities are found in the relatively poorly sorted, dolomitized, leached skeletal limestones with porous matrix (up to 30 percent porosity and 1000 plus millidarcies permeability). These porous dolomites grade laterally in a predictable way into tight, well sorted, cemented, skeletal limestones. The chart of Figure 2

ELKTON CARBONATES

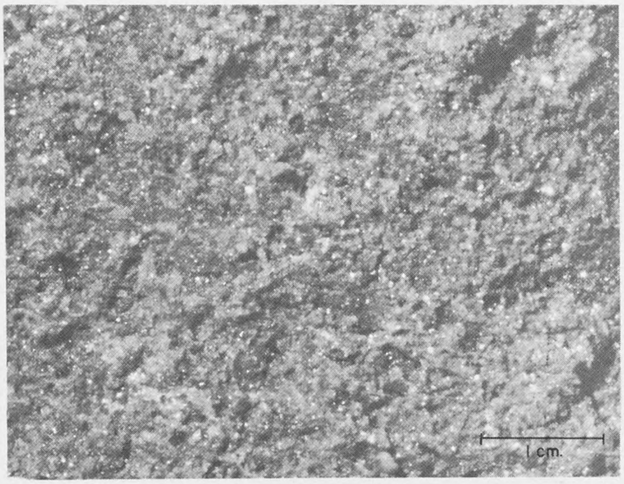
DEMONSTRATION SERIES ILLUSTRATING PROGRESSIVE DESTRUCTION OF SKELETAL GRAIN OUTLINES DURING DOLOMITIZATION



(A)
Dolomitized unleached skeletal limestone
with porous matrix
Horizontal core



(B)
Dolomitized partially leached skeletal limestone
with porous matrix
Horizontal core



(C)
Dolomitized partially leached skeletal limestone
with porous matrix. (medium to coarse sub-
euhedral dolomite)
Horizontal core

PLATE II

illustrates that porosity logs readily distinguish these markedly different facies types in the Sundre-Westward Ho fields. The cemented skeletal limestones were probably laid down under initial high wave energy or shoal conditions in which the comminuted, micro-to finely granular material, which contributes to matrix porosity, was winnowed out and deposited under lower energy conditions.

The rock photograph sequence of Plate II demonstrates that locally there is a progressive destruction of skeletal grain outlines during the process of dolomitization. The end result of such dolomitization is the production of medium to coarse crystalline dolomite, the generic implications of which are in doubt. This type of material is quite common in the stratigraphic column of the Western Canada basin (e.g. the Devonian Nisku formation). When definite skeletal outlines have been destroyed and replaced by medium to coarse dolomite crystals, then a crystallinity (dolomite grain size) ratio map would be of great value in distinguishing between dolomitized fragmentals and dolomitized lime-mud areas.

MICRO-TO FINE RHOMBIC DOLOMITES WITH LEACHED FOSSIL CASTS

The rock photograph of Plate I.D is representative of this locally developed group of Elkton carbonates with effective porosity. These carbonates are considered to be the dolomitized equivalents of comminuted, skeletal or non-skeletal grains in current agitated areas. Porosity in this class of carbonates is high, but permeability is high only when fossil casts supplement the pore space between the packed granules. Complex intermixtures of this group of carbonates with effective matrix and vug porosity, and chalky to earthy carbonates with no effective porosity are usually found at the top of the Elkton member.

DOLOMITIZED LIME MUDS WITH LEACHED FOSSIL CASTS AND LEACHED SKELETAL TO NON-SKELETAL CARBONATES WITH A TIGHT, ORIGINALLY LIME-MUD MATRIX

Lime muds, probably because of an original high fluid content, alter easily to a crypto-to microcrystalline, anhedral to subhedral, interlocking type of dolomite with little or no effective porosity. However, the skeletal or non-skeletal grains embedded in this original lime mud material are locally leached to produce generally poorly effective vug porosity.

CONCLUSION

With regard to exploration philosophy on unconformity, 'porosity-wedge' plays, this study again reveals the necessity for reconstruction of the sedimentation history of the prospective, eroded unit. The mapping of dissected, primary permeability barriers (cemented skeletal limestones) at or near the Elkton subcrop is just as important to oil and gas exploration as is the recognition of, e.g. impermeable, marginal anhydrites at or near the subcrop of the Mississippian shelf carbonate cycles in the Souris Valley area of southeastern Saskatchewan.

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THE BLAIRMORE GROUP IN THE SUBSURFACE OF ALBERTA

L. E. WORKMAN [1]

Abstract

Cross-sections extending through the subsurface from Fort St. John, British Columbia, eastward to the Fifth Meridian in Alberta, thence southward to the International Boundary, show the stratigraphic relationships of the various units of the Blairmore group. Emphasis is placed on the widespread occurrence of the Glauconitic sand; it is proposed that it be known hereafter as the Bluesky formation. The subsurface sections are 'tied in' to an outcrop section along Sheep River, southwest of Calgary.

Introduction

This study was made primarily to show stratigraphic relationships of the Glauconitc sand in Alberta. Three cross-sections: A-B, B-C, and D-E extend through wells along the lines shown on the index map, Figure 1. Cross-section A-B (Fig. 2) extends eastward from Pacific Fort St. John No. 23 in the Peace River Block, British Columbia, to Barnsdall West Wabiskaw No. 1 near the Fifth Meridian. Cross-section B-C (Fig. 3) extends southward from Barnsdall West Wabiskaw No. 1, and closely follows the Fifth Meridian to the International Boundary. Cross-section D-E (Fig. 2) ties in the latter section to an outcrop of the Blairmore group along Sheep River, southwest of Calgary. An additional cross-section (not included with this paper) shown by Workman (1958) 'ties in' to cross-section B-C at Canadian Superior North Beiseker No. 1 (well 12) and shows stratigraphic relations northeastward.

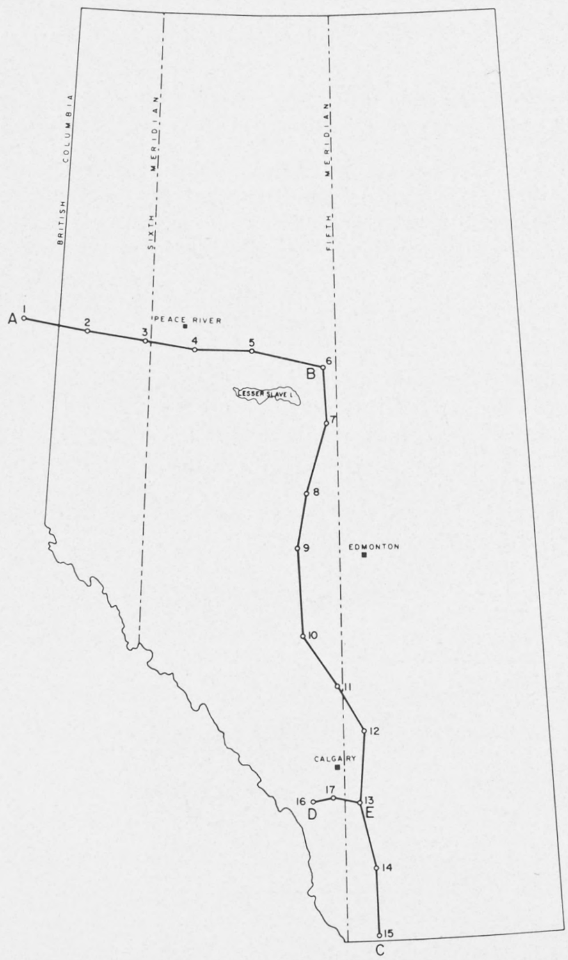


FIGURE 1

1 Canadian Stratigraphic Service Ltd., Calgary, Alberta.

Datum for the cross-sections is the top of the Paddy-Cadotte, Viking, and Bow Island sands. Although the average distance between wells may be near 50 miles, the logs of most other wells between each successive well shown on the cross-sections were examined in preparation of this paper.

Observations of Blairmore stratigraphy in addition to those with special reference to the Glauconitic sand are recorded. No attempt has been made to give a systematic review of the lithology of each stratigraphic unit; these descriptions may be found elsewhere. Although only electric logs are utilised in the cross-sections, the lithology as shown in logs of the Canadian Stratigraphic Service Ltd. is the basis of these observations.

The wells, and the one outcrop, used in the cross-sections, are numbered as follows for quick reference.

CROSS-SECTION A-B

1. Pacific Fort St. John No. 23
   Lsd. 3, Sec. 29, Twp. 83, Rge. 18, W6M.
2. Texaco Josephine Creek A-1
   Lsd. 6, Sec. 31, Twp. 82, Rge. 9, W6M.
3. Shell-B. A. Bluesky No. 1
   Lsd. 4, Sec. 29, Twp. 81, Rge. 1, W6M.
4. Shell Kimiwan No. 1
   Lsd. 2, Sec. 26, Twp. 80, Rge. 20, W5M.
5. California Standard Atikameg Province No. 1.
   Lsd. 4, Sec. 22, Twp. 80, Rge. 12, W5M.
6. Barnsdall West Wabiskaw No. 1
   Lsd. 11, Sec. 17, Twp. 78, Rge. 2, W5M.

CROSS-SECTION B-C

6. Barnsdall West Wabiskaw No. 1
   Lsd. 11, Sec. 17, Twp. 78, Rge. 2, W5M.
7. Pacific-Fina Bradley No. 1
   Lsd. 1, Sec. 35, Twp. 70, Rge. 2, W5M.
8. Imperial Neerlandia 10-12
   Lsd. 10, Sec. 12, Twp. 61, Rge. 5, W5M.
9. Merrill-Home et al Magnolia 15-32
   Lsd. 15, Sec. 32, Twp. 53, Rge. 6, W5M.
10. Texaco-McColl Alhambra A-2-1
    Lsd. 2, Sec. 1, Twp. 42, Rge. 6, W5M.
11. White Rose-C. & E-H.B. Innisfail 11-11
    Lsd. 11, Sec. 11, Twp. 35, Rge. 1, W5M.
12. Socony-Canadian Superior North Beiseker No. 1
    Lsd. 8, Sec. 11, Twp. 29, Rge. 26, W4M.
13. Richfield-Medallion Mazeppa 6-16
    Lsd. 6, Sec. 16, Twp. 19, Rge. 27, W4M.
14. Socony Granum No. 1
    Lsd. 1, Sec. 25, Twp. 11, Rge. 26, W4M.
15. B. A. Carway 15-15
    Lsd. 15, Sec. 15, Twp. 1, Rge. 26, W4M.

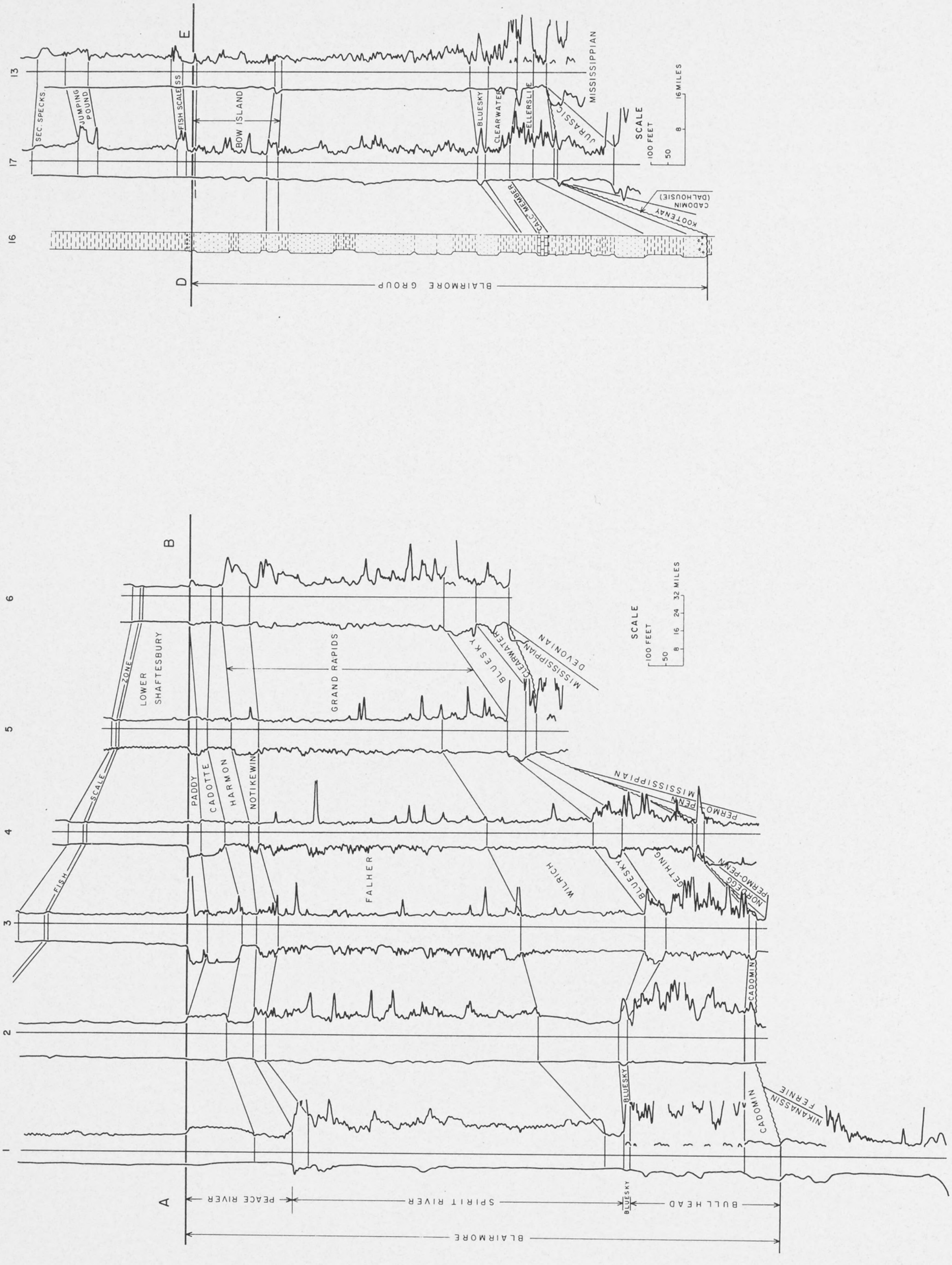

13
17
16
E
D
SEC. SPECKS
JUMPING POUND
FISH SCALE SS
BOW ISLAND
BLUESKY
CLEARWATER
ELLERSLIE
JURASSIC
MISSISSIPPIAN
CALC MEMBER
KOOTENAY
CADOMIN (DALHOUSIE)
BLAIRMORE GROUP
SCALE
100 FEET
50
8
16 MILES
1
2
3
4
5
6
A
B
FISH SCALE ZONE
LOWER SHAFTESBURY
PADDY
CADOTTE
HARMON
NOTIKEWIN
GRAND RAPIDS
FALHER
WILRICH
BLUESKY
GETHING
NORDEGG
PERMO-PENN
MISSISSIPPIAN
DEVONIAN
CLEARWATER
CADOMIN
NIKANASSIN
FERNIE
PEACE RIVER
SPIRIT RIVER
BULLHEAD
BLAIRMORE
SCALE
100 FEET
50
8
16
24
32 MILES

FIGURE 2

CROSS-SECTION D-E

16. Outcrop on Sheep River figured by Glaister
    (1958, cross-section AA') Sec. 35, Twp. 19, Rge. 5, W5M.

17. Shell-Anglo Canadian Pine Creek No. 1
    Lsd. 12, Sec. 12, Twp. 20, Rge. 2, W5M.

13. Richfield-Medallion Mazeppa 6-16
    Lsd. 6, Sec. 16, Twp. 19, Rge. 27, W4M.

Bluesky Formation

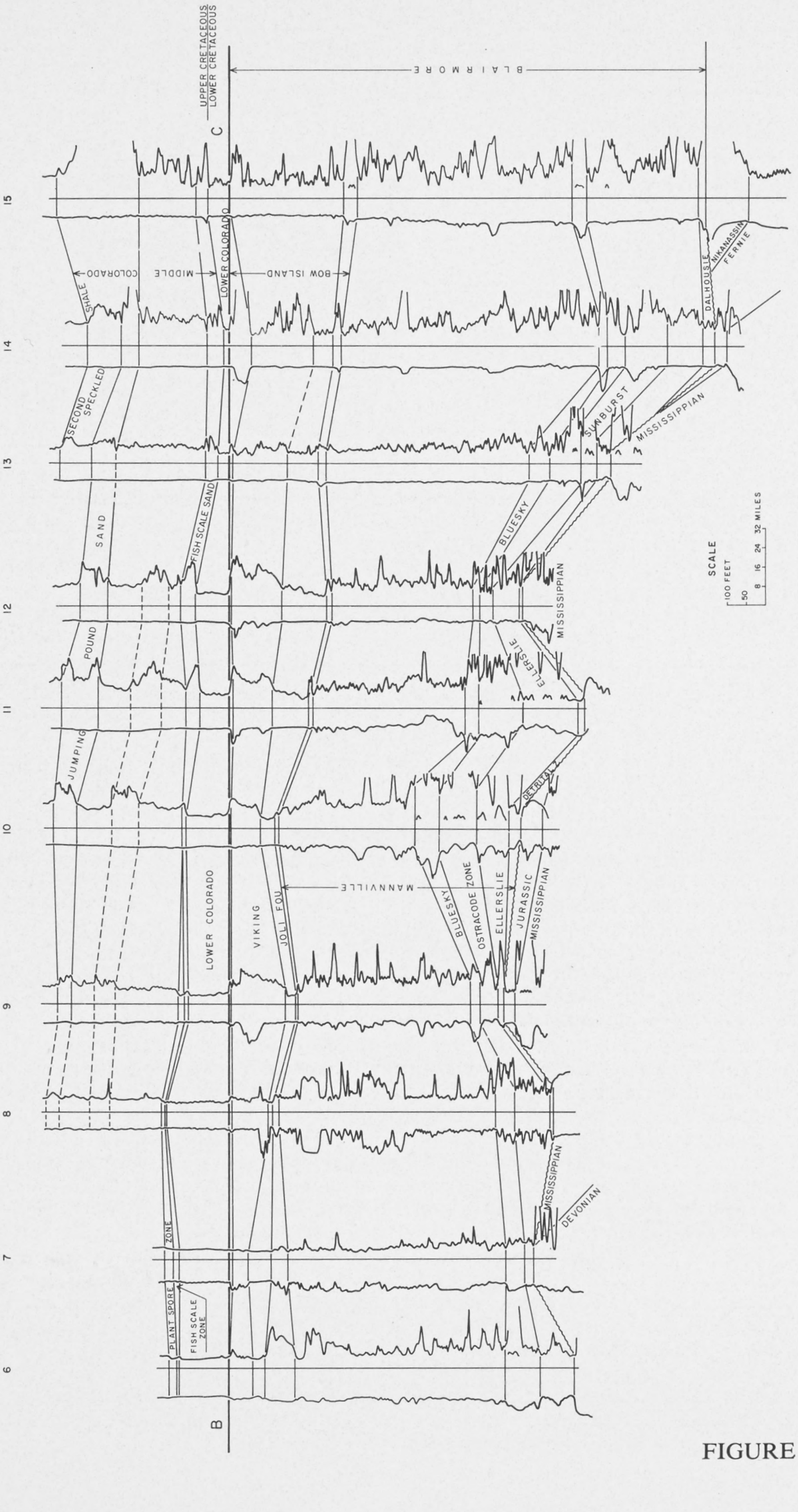
The Bluesky formation was originally defined by the Alberta Study Group (1954) as consisting mostly of glauconitic sandstone but containing an ostracode-bearing dark grey to black shale at its base. It was suggested that subsequent studies might make it desirable to separate the sand and shale into two geological units. The formation was defined at Shell-British American Bluesky No. 1 (Fig. 2, well 3).

Cross-section A-B shows the stratigraphic position of the Bluesky sandstone in the Peace River region (Fig. 2, wells 1 to 5) to be in the lower part of the Blairmore group. It is overlain by dark grey shale of the Wilrich member of the Spirit River formation, and underlain by the Gething formation which consists of dark grey shales, thin coals, and interbedded sandstones. General geological usage has rejected or disregarded the inclusion of the ostracode-bearing shale under the sandstone as part of the Bluesky formation. In this paper the author wishes to give recognition to this fact, and proposes that the term Bluesky be limited to the sandstone.

Cross-section A-B shows that the Bluesky sandstone extends through the location of Barnsdall-West Wabiskaw No. 1 (well 6). The Oil and Gas Conservation Board, Schedule of Wells (1950, p. 12) lists this sand as the Wabiskaw member, — a sandstone containing oil and gas in the Wabiskaw area. In the 1954 and following Schedules, the sand is reported as glauconitic. Badgley (1952) described the Wabiskaw and correlated it with the so called Glauconitic sandstone of the Leduc-Stettler area.

In summarizing the Lower Cretaceous strata of the Leduc area, Layer (1949) designated 255 feet of interbedded sandstones and shales in the middle of the section as the Glauconitic Sand series, and pointed especially to the presence of glauconitic quartz sandstones in the lower part. The base of the Glauconitic Sand series was placed at the top of the underlying ostracode-bearing shales. Since then the Glauconitic sand, restricted by common usage to the lowest part of Layer's Glauconitic Sand series, has been widely recognized in Alberta. In the Leduc area it reaches a thickness of about 70 feet. Stratigraphic relationships in the Leduc region are similar to those shown in Figure 3 (wells 7, 8 and 9). In tracing the Bluesky sandstone southward in cross-section B-C, it is apparent that the Glauconitic sand is the Bluesky.

Maps by Workman (1958) show that the Glauconitic sand is widespread in southern Alberta. In the early development of the Turner Valley field it was probably the Glauconitic sand that produced oil in the Home No. 1 well, (Lsd. 10, Sec. 20, Twp. 19, Rge. 2, W5M.) which was completed in 1929. Hume (1938) reports that in 1927 this well encountered a sand at 4,560 feet that "became known as the Home sand. It is a white or grey rather sugary textured quartz sand which has been widely recognized even where it is not oil or gas bearing." Further, he says the Home sand (stratigraphic position in this general area) is "900 to 950 feet from the top of the Blairmore and is underlain by a series of limy sandstones alternating with dark shales." Thus the Home sand appears undoubtedly to be the Glauconitic sand. However, the log of the Home No. 1 well is not now available and the Oil and Gas Conservation Board (1949) records the top of the Home sand at 4,560 feet (2,610 feet below the top of the Blairmore.) The difference in interval below the top of the Blairmore from that given by Hume is probably due to repetition of portions of the Blairmore due to thrust faulting in this well. The Home No. 1 well is about 8 miles northwest of well 17 in cross-section D-E (Fig. 2), where the Glauconitic sand is about 800 feet below the top of the Blairmore, and the increase to 900 feet at the Home well would be normal westward stratigraphic thickening. The use of the term Home sand has been limited to the area close to Turner Valley.



UPPER CRETACEOUS
LOWER CRETACEOUS
C
B
BLAIRMORE
15
14
13
12
11
10
9
8
7
6
SHALE
COLORADO
MIDDLE
LOWER COLORADO
BOW ISLAND
DALHOUSIE
NIKANASSIN
FERNIE
SECOND
SPECKLED
SUNBURST
MISSISSIPPIAN
SAND
FISH SCALE SAND
BLUESKY
POUND
ELLERSLIE
JUMPING
DETRITAL
LOWER COLORADO
VIKING
JOLI FOU
MANNVILLE
OSTRACODE ZONE
JURASSIC
DEVONIAN
PLANT SPORE
ZONE
FISH SCALE
ZONE
SCALE
100 FEET
50
8
16
24
32 MILES

FIGURE 3

CORRELATION CHART

<table>
<tr><th colspan="2">PEACE RIVER</th><th>NORTH CENT. ALTA.</th><th colspan="2">EDMONTON AREA.</th><th colspan="2">SOUTHERN ALTA.</th></tr>
<tr><td rowspan="3">PEACE R.</td><td>PADDY</td><td rowspan="2">PELICAN</td><td colspan="2" rowspan="2">VIKING</td><td rowspan="10">BLAIRMORE GROUP</td><td rowspan="4">BOW ISLAND</td></tr>
<tr><td>CADOTTE</td></tr>
<tr><td>HARMON</td><td>JOLI FOU</td><td colspan="2">JOLI FOU</td></tr>
<tr><td rowspan="3">SPIRIT RIVER</td><td>NOTIKEWIN</td><td rowspan="3">GRAND RAPIDS</td><td rowspan="6">MANNVILLE SUBGROUP</td><td>"GRIT"</td></tr>
<tr><td>FALHER</td><td rowspan="2">"Coaly series"
Upper part "glauconitic sand series"</td><td rowspan="2"></td></tr>
<tr><td>WILRICH</td></tr>
<tr><td colspan="2">BLUESKY</td><td>BLUESKY</td><td>BLUESKY</td><td>BLUESKY</td></tr>
<tr><td rowspan="3">BULLHEAD</td><td rowspan="2">GETHING</td><td>CLEARWATER</td><td>CLEARWATER (OSTRACODE ZONE)</td><td>OSTRACODE ZONE</td></tr>
<tr><td>Mc MURRAY</td><td>ELLERSLIE</td><td>SUNBURST</td></tr>
<tr><td>CADOMIN</td><td>(Absent)</td><td colspan="2">(Absent)</td><td>DALHOUSIE</td></tr>
</table>

FIGURE 4

The cross-sections and maps by Workman (1958) demonstrate that the sand variously called Bluesky, Wabiskaw, Glauconitic, Home, Isley, and Kerkhoff is a wide-spread stratigraphic unit and selection of a suitable name is appropriate. This sand is not the only one in the Blairmore group that is glauconitic, and furthermore, the term 'Glauconitic sand' is not an approved geological name for a formation. The name Home is not now widely used and has some slight degree of uncertainty as to its applicability to the Glauconitic sand. The Isley (Nauss, 1945) is probably the same sand (Badgley, 1952), but the name is used only locally. The Kerkhoff sand, named after a farm in eastern Alberta, is probably the same sand, but its use was even more local and has probably been discontinued. The name Wabiskaw is a suitable one and is well typified by the sand in West Wabiskaw No. 1 (Fig. 2, well 6). Regardless of this, and because the term Bluesky has had previous wide-spread use, and is not likely to be replaced in the Peace River region by any other name that may be recommended, it is here proposed that the term Bluesky formation be re-defined and extended from the Peace River region to designate the sandstone heretofore popularly called the Glauconitic sand, wherever it is recognizable. In this re-definition of the Bluesky formation, the former inclusion of the ostracode shale in the Bluesky formation is abandoned.

Blairmore Correlations

Correlations of the various formations and members of the Blairmore group are shown in the correlation chart (Fig. 4).

By means of cross-section D-E (Fig. 2) which extends correlations to the Foothills, it is demonstrated that the Blairmore group includes all formations between the top of the Bow Island sandstone series to the base of the Cadomin conglomerate. It has been common practice in subsurface studies to apply the term Blairmore only to Lower Cretaceous strata in the interval below the Joli Fou shale, or the Bow Island sandstone series. The proper term for this interval is Mannville (Nauss, 1945); a fact generally recognized but not generally followed because it has not been demonstrated to complete satisfaction. Inasmuch as the Mannville is a portion of the Blairmore group, and units included in it are formations, the Mannville itself should be considered a sub-group.

These cross-sections suggest that the Paddy formation, which is a coarse-grained sandstone with thin basal shaly and coaly beds overlying the Cadotte sandstone in the Peace River region, is the same as the thin chert-pebble sand that overlies the Viking widely through central Alberta. This may be the same sand as that shown above the top of the Blairmore in the outcrop section by Glaister (1958), though the section has been reproduced here as constructed by Glaister (Fig. 2, well 16).

From the cross-sections, it appears that the Cadotte and Viking sandstones are the same stratigraphic unit. It follows that the Harmon and Joli Fou shales are also the same. This theory is not acceptable to Wickenden (1951) and Stelck (1958), who believe that the Viking and Joli Fou are stratigraphically higher than the Cadotte and Harmon, and that the possibility exists that the Paddy is equivalent to the Viking and the upper part of the Joli Fou. To the writer it is significant that:

1. The Cadotte and Viking are typically very fine glauconitic salt-and-pepper sandstones, and the Harmon and Joli Fou are typically dark brownish-grey marine shales; in no significant way have they been shown to the lithologically different from each other.

2. The Viking and Paddy are not similar to each other in lithology, nor does the small amount of coaly shale underlying the Paddy suggest in any way the lithology of the Joli Fou. On the other hand, the Paddy does resemble the thin beds of coarse salt-and-pepper sand overlying the Viking throughout the subsurface in much of Alberta.

3. The stratigraphic continuity of Cadotte to Viking and Harmon to Joli Fou can be followed in the cross-sections, whereas the subsurface continuity of Paddy to Viking, the lateral continuation of basal Paddy to become the Joli Fou eastward, and the disappearance of the Cadotte and Harmon to the east or southeast of the Peace River area have not been demonstrated.

Logical drawing of correlation lines tend to show that the Notikewin sandstone of the Peace River region is laterally represented by the basal Colorado grit in central and southern Alberta. This may be questioned somewhat on the basis that the Notikewin appears to grade downward into the Falher and the grit appears to lie on previous sediments at an abrupt contact. The grit is now considered as the basal deposit of the Joli Fou shale and the Bow Island sandstone series. Further study will be necessary.

Cross-section A-B (Fig. 2) shows a lenticular development of the Wilrich member in the Peace River region. Whether it is a distinct black shale unit bounded at its top by a continuous surface of deposition or it changes facies laterally to the "Falher type" sand and shale is not now evident. In view of the westward gradual thickening of the overlying Falher in contrast with the lenticular character of the Wilrich, it is suggested that the first condition is true. This would lead to the assumption that sediments equivalent in time of deposition to the Wilrich are not present in well 6 and southward in the area traversed by cross-section B-C; and that there is a break in sedimentation equivalent to the Wilrich in a wide area in Alberta.

Badgley (1952) shows in general that the Mannville sediments above the Bluesky compose the Grand Rapids formation and those below, down to the top of the McMurray sandstone, the Clearwater formation. However, he shows the Bluesky (Wabiskaw, Isley sands) crossing the boundary between the two formations, being in some places in the top of the Clearwater and in others in the bottom of the Grand Rapids formation. Since the Bluesky formation is here demonstrated to be a stratigraphic unit that may be separated from Grand Rapids and Clearwater, each of these two formations thereby gains a distinct unity that heretofore was not apparent. The Grand Rapids is a salt-and-pepper sand with interbedded shales and coals, between the Joli Fou and the Bluesky. The Clearwater consists of marine and brackish-water dark-grey shales, argillaceous limestone, and siltstone beds and lenses lying between the Bluesky and the McCurray (Ellerslie) sands. This is the Ostracode zone as the term is generally used, and thus this stratigraphic interval may be called the Clearwater formation.

The writer believes that the McMurray, Ellerslie, and Sunburst sandstones are all correlatable but are intimately related to the Ostracode zone, or Clearwater formation, in such a way that the tops of the sands cannot be correlated. The Clearwater grades down into these sands with increasing numbers of sandstone and siltstone lenses until the sandstone becomes predominant. This predominance of sandstone over shale content is the basis for the writer's selection of the top of the Ellerslie. The top of the Sunburst is usually placed somewhat lower, where the quartz sandstone shows pore filling of putty-like clay. The Sunburst type of sand can be seen in south-central Alberta, as well as in its area of typical development in southern Alberta.

Westward from central Alberta into the Peace River region and British Columbia the Clearwater formation is correlated with the upper part of the Gething (Fig. 2). Here the formation consists of salt-and-pepper sandstones interbedded with the quartz sands, though the dark brownish-grey shales persist. The lower part of the Gething contains much quartz sand similar to that of the Ellerslie, but it is not possible to recognize the Ellerslie as a unit.

The Cadomin conglomerate is the basal Blairmore deposit above the pre-Blairmore unconformity. In the Peace River region it constitues a basal unit of the Bullhead group and the sediments above it to the Bluesky are called the Gething formation. In the south part of the Alberta Foothills this conglomerate is also called the Dalhousie (Fig. 3). Southward in Montana it may be the Cutbank. Comparison of wells 1 and 15, at opposite ends of cross-sections A-B and B-C. (Figs. 2 and 3) shows a remarkable similarity in the electric logs from the Bluesky down. The sediments, however, are different in that red and green shales are present in the section in the south, whereas the dark brownish-grey shales typical of the Ostracode zone are common in the north.

Cross-sections A-B and D-E illustrate to some extent the westward basinal thickening of the sedimentary units over the pre-Blairmore unconformity. The Cadomin, (first Cretaceous sediments to be deposited) is present only in the deeper part of the Alberta syncline.

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VIKING DEPOSITION IN THE SOUTHERN ALBERTA PLAINS

H. K. ROESSINGH [1]

Abstract

An examination of Viking cores from wells located between Townships 14 and 34 from the Saskatchewan border to the Foothills belt was used as the basis for this paper. A number of micro-structural features are considered to be evidence of penecontemporaneous hydroplastic deformation. These features contradict the theory that the Viking is a shore or off-shore sediment, deposited during repeated minor transgressions and regressions. Deposition by turbidity currents is offered as an alternate interpretation.

Introduction

This paper discusses the Viking formation and its equivalent the Bow Island of southern Alberta, between the 4th Meridian and the eastern edge of the Disturbed belt and between Townships 14 and 34 inclusive (Fig. 1). Comparatively little has been published about the Viking since production was found in this formation 50 years ago. The reader is referred to the references for a selected list of published Viking papers. Although useful information is contained in these papers, much additional work will have to be done before definite answers can be given to the many problems connected with the deposition and distribution of the Viking. This paper is intended as a contribution toward that end.

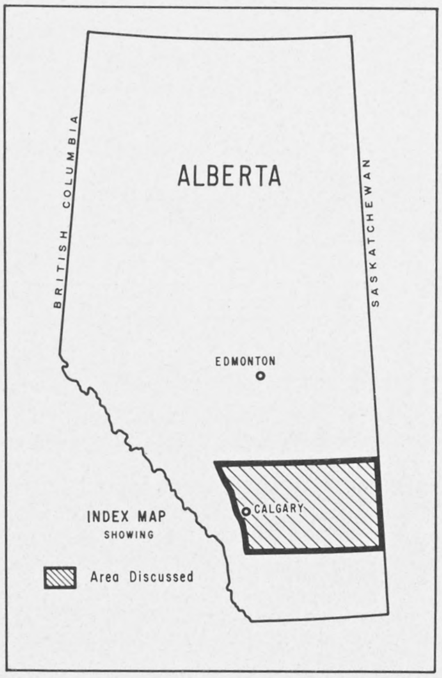

FIGURE 1

An examination of available cores from the Viking has been used as a basis for the present study (Fig. 2). This core examination was, where necessary, supplemented by examination and correlation of electric logs and micrologs. Results of Viking drillstem tests were used for the preparation of Figure 2. It is realized that the method used in this study has limitations, since the Bow Island was cored from top to base in only one well. This well, Bralsaman Taber No. 1, in Lsd. 6, Sec. 19, Twp. 8, Rge. 15, W4M., is situated south of the area discussed in this paper. Cores available from other wells are representative of part of the Viking, usually the upper part; thus little core data is available for other parts of the Viking interval.

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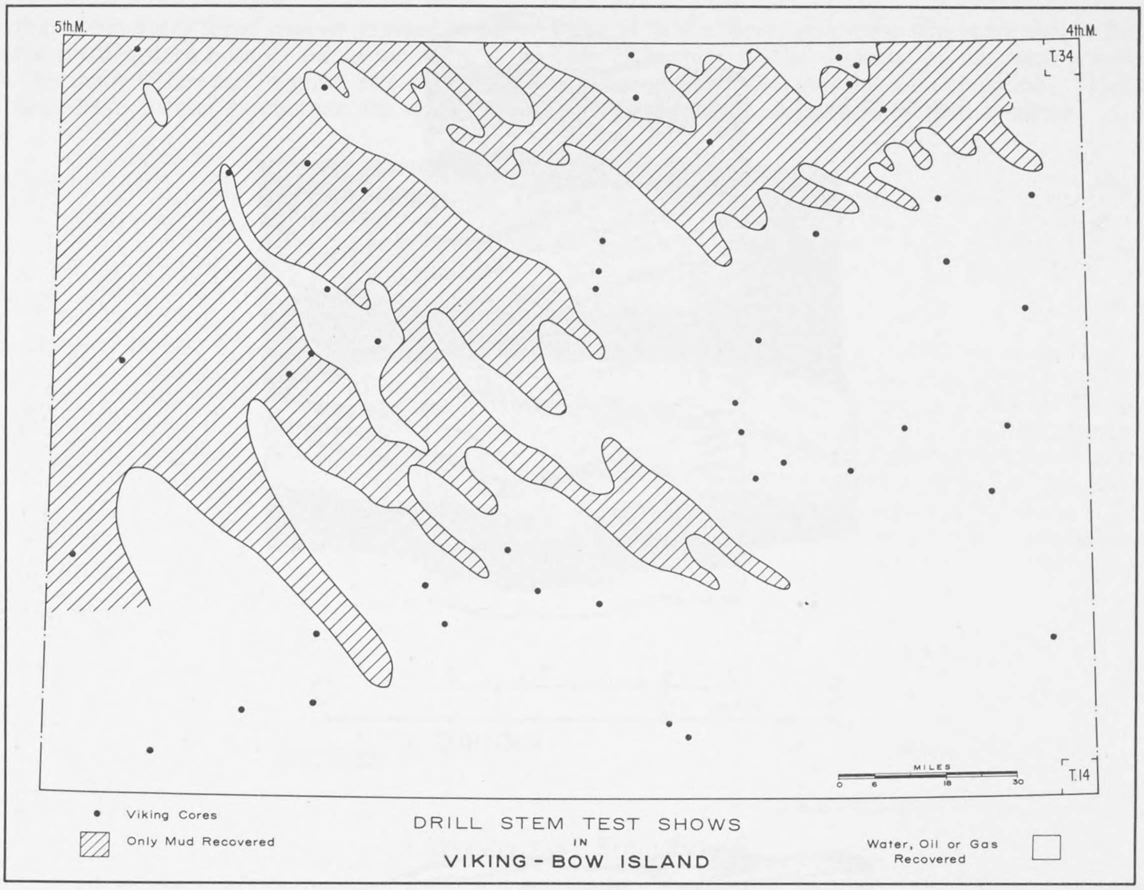

FIGURE 2

Age and Correlation

Although the Viking was classified as a member by Gammell (1955), the author is in agreement with later publications in which it has been classified as a formation (Stelck, 1958).

The Viking, and its equivalents, is a shaly sand and silt formation situated between two shale sections in the upper part of the Lower Cretaceous. An Upper Albian age has been assigned to this areally extensive unit (Stelck, 1958). It is known in different areas under a variety of names, from Paddy in the Peace River area (Stelck, 1958) to Newcastle sand in the Powder River Basin of northeastern Wyoming. The Alberta Oil and Gas Conservation Board, in its most recently published correlation table (February 27, 1959), correlates the Viking with the Crowsnest volcanics. Folinsbee (1957) reported a considerable difference in age between the two on the basis of potassium-argon age determinations.

As the underling Joli Fou formation thins to practically zero in the region adjoining the Foothills to the east, physical correlations in this area and in the Disturbed belt become highly conjectural. This question will remain unanswered until more paleontological information becomes available. The Viking sand pinches out to the northeast in the St. Paul area, Twp. 58, Rge. 9, W4M. (Gammell, 1955).

Texture

Sands having a complete range in grain size, as well as silt and conglomerates, are present in the Viking. These clastics are consistently well sorted. Although Glaister (1959) reports an upward increase in grain size in individual sands and Gammell (1955) states that there is a gradual decrease in grain size from southwest to northeast, neither consistent stratigraphic nor areal gradation of Viking sands was noted by the author after careful mapping of grain sizes of all Viking sands. In addition to one grain size at the fine end of the scale, which occurs over practically

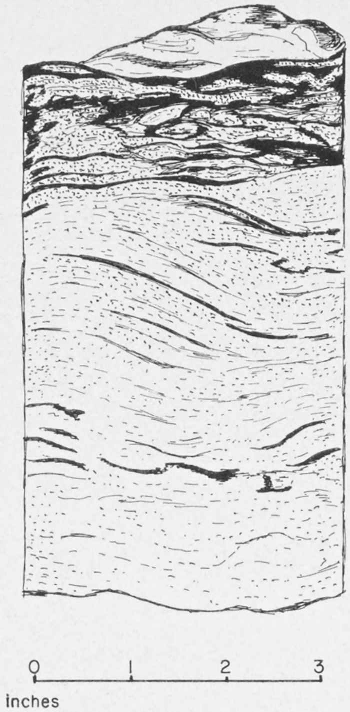

FIGURE 4

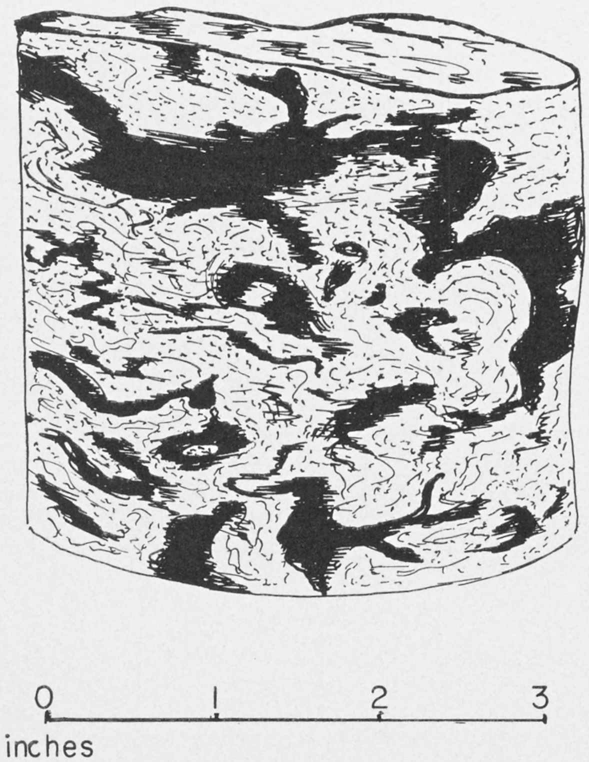

FIGURE 5

the whole area, some coarser grained beds were found in the west, and some silts were mapped at the northeastern limit of the area. This is the only indication of the distance of the sand source. The main difference in grain size seems to be connected with the manner of deposition. Thick beds have coarser sands than the more frequent thin sand layers, regardless of their location.

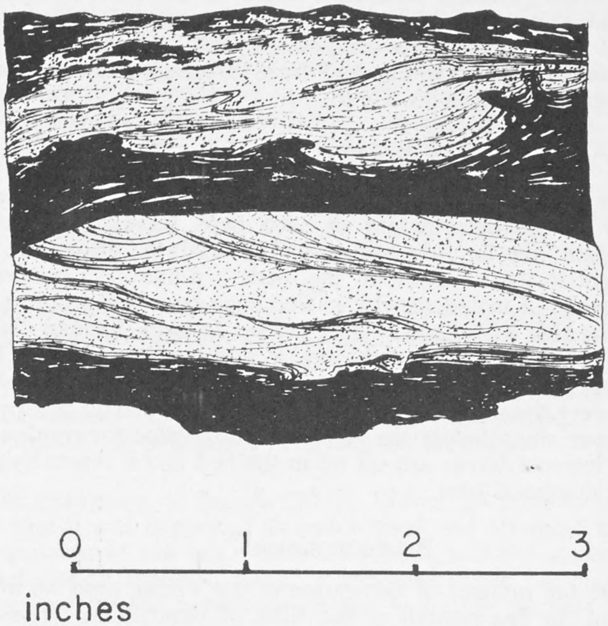

FIGURE 3

Sedimentary Structures

Micro-structural features of the Viking sand are a classical example of contemporaneous deformation. With few exceptions, all the examined cores showed one or more of the following features: (1) crossbedding, (2) ripple-marks, (3) flow structures, (4) slump structures, and (5) convolute bedding. All of these occur in alternating sand and shale sequences.

CROSSBEDDING

Crossbedding occurs in sand lenses from 1 to 10 centimetres thick. In some cases, e.g. B. A. Halliday 7-9-28-14 (Lsd. 7, Sec. 9, Twp. 28, Rge. 14, W4M), the sand has obviously filled irregularities in the underlying shale. The top of the sand bed is usually smooth, probably scoured (Fig. 3). The crossbedding is on a very small scale but shows all the characteristics of large-scale crossbedding. The beds are concave upward. At the upper end, they are convex and grade into horizontal beds. In practically all cases, this convex upper part has been eroded since the original deposition. In some cases only foreset beds, apparently filling a small depression in the sea bottom, are present (Fig. 3).

RIPPLE-MARKS

A few examples of ripple-marks have been found, for example, at Calvan Handhills 7-22 in Lsd. 7, Sec. 22, Twp. 29, Rge. 14, W4M. The size of a core does not always permit a clear cut interpretation of this feature. Wherever found the ripple-marks form the top of a horizontally bedded clean sand, and are usually overlain by shale.

FLOW STRUCTURES

Flow structures are common and often occur with crossbedding (Fig. 4). Some of the flow structures show a striking similarity to those described by Shrock (1948, p. 159). According to Kuenen (1950) and Shrock, these structures as well as slump structures referred to below are the result of movement of highly water-saturated sand and mud along gentle slopes on the sea bottom. This conclusion will be discussed in more detail.

SLUMP STRUCTURES

Slump structures occur in almost all cores examined, irrespective of geographical location. The occurrence of slump structures interbedded with undisturbed lentils is proof of their syngenetic origin. The disturbed beds are from a few centimetres to several metres thick. A large number of structural features classified as slump structures occur in these beds: folds, miniature nappes, minor faults, shearing, and overturned beds. All these phenomena occur in alternating sand and shale laminae, usually not more than a few millimetres thick. In two cases it was observed that the culminations of the small scale anticlines had been eroded and were overlain by horizontal beds. Slump structures are illustrated in Figure 5.

CONVOLUTE BEDDING

Convolute bedding is a phenomenon very similar in appearance to slump structures. According to Kuenen (1953), the deformation of such beds increases in intensity upwards and then gradually dies out again: the laminae are never ruptured; the distortions are round; no external irregularities are present in the thickness of the beds. Some occurrences showing all these characteristics were observed. Kuenen concludes that such beds are proof of deposition by turbidity currents. He explains this as follows: "The sandy deposits formed by a turbidity current are in a highly mobile condition like quicksand or saturated beach sand that is patted with a flat object. The development of pockets in nature and in the experiments testifies to this mobilty. In this quasi-liquid state very small forces will suffice to cause plastic deformations. If the velocity of the turbidity current sinks below the upper limiting value for ripple-marking and a ripple pattern starts to develop, internal forces are set up in the bed and it reacts by plastic deformation." These conclusions will be discussed later.

PALEOGEOGRAPHY

In order to determine the manner of deposition of the Viking sand we must try to reconstruct the regional topography of the sea bottom at the time of deposition. The isopach map of the interval top Devonian to top Blairmore (Fig. 6) can be used as a rough guide for this purpose.

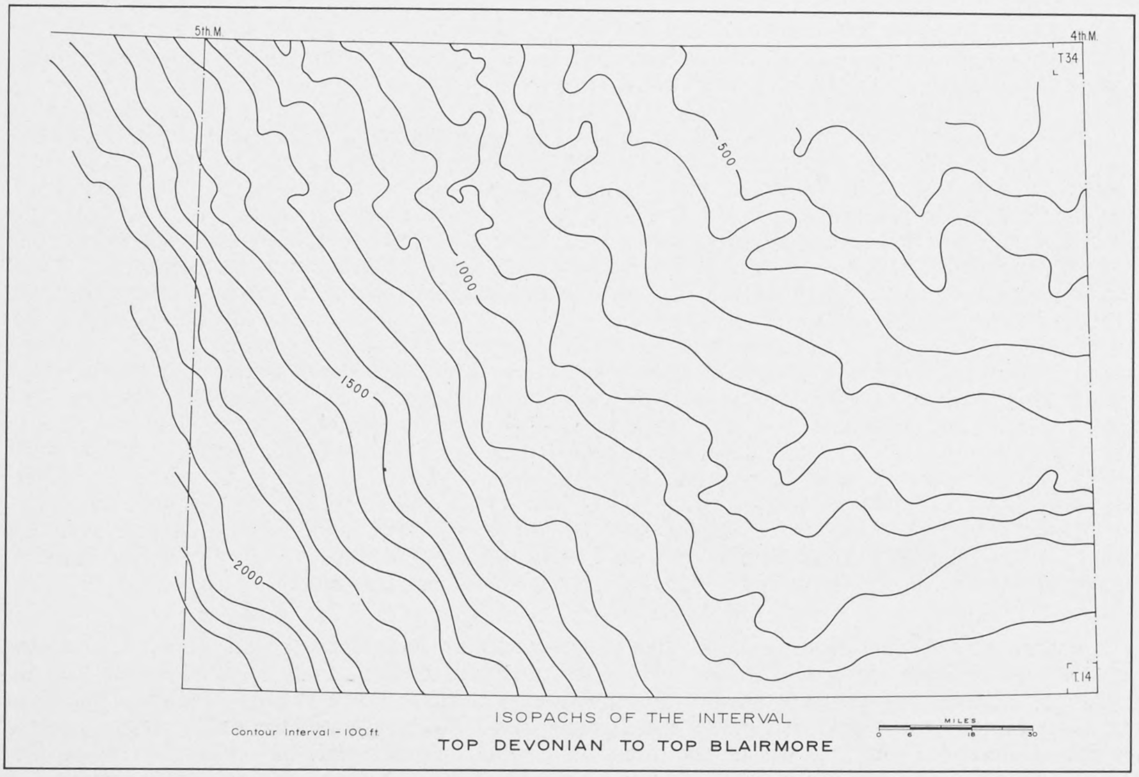

FIGURE 6

This map shows the irregularities in the sea bottom at the time of the post-Blairmore transgression. If we consider that an average slope of the sea bottom of one degree would result over the width of Alberta in a drop of close to 15,000 feet, it is easy to understand that in all likelihood the slope was even less than 1 degree.

We may conclude that during upper Colorado time, the Great Plains was covered by a shallow sea with a flat or only slightly sloping bottom, which was gradually subsiding. To the west there existed a rising land mass with a moderate amount of volcanic activity, as evidenced by the frequent occurrence of bentonites in the Viking and Bow Island. This volcanic activity was probably post-Crowsnest. Folinsbee (1957) calculated that the Viking was deposited approximately 30,000,000 years after the culmination of the volcanic activity which was the source of the Crowsnest volcanics.

Deposition

Traditionally, features like crossbedding, current bedding, ripple-marks, and recurrence of pebble beds have been cited as evidence of frequent fluctuations of sea level. The depth of the water therefore, during Viking deposition can at no time have been very great. The question arises, why shales have been deposited between the coarse-grained beds, and why pebble horizons occur within the shales. One explanation is that these textural changes may be the result of changes at the source of the sediments involving the mechanics of transportation.

With the notable exception of Beach (1955, 1956), all authors writing on the Viking and its equivalents agree that it was deposited as beach sand and off-shore sand bars, during repeated regression and transgression of the sea. Glaister (1959, p. 638) states: "The Bow Island sandstones were deposited during repeated minor regressions within the major transgression." Stelck (1958) calls it shore and off-shore bars developed along the borders of the *Haplophragmoides gigas* sea. Gammell (1955) is less definite in his interpretation as he calls the Viking "probably the result of a momentary acceleration in the degradation of the highland to the southwest."

This reasoning implies that the upper Colorado sea was so shallow that minor fluctuations of the sea level caused shifts of the shoreline of possibly hundreds of miles. A close examination of the available cores reveals that this concept is untenable.

Bentonites are common in the Viking and occur in wells as far apart as Calstan. Parkland 4-12 in Lsd. 4, Sec. 12, Twp. 15, Rge. 27, W4M. and some of the Grassy Island Lake wells in Twp. 32, Rge. 7, W4M. In these wells the bentonites occur in approximately the same stratigraphic position relative to the top of the Viking. If it is true that bentonite is a volcanic ash deposited in a very short time over a large area and that, therefore, bentonites are good time markers, the occurrence of bentonites in the same stratigraphic position contradicts the concept of a transgression and regression. If the Viking represents shore and off-shore bars, it must necessarily trangress time lines.

The micro-structures described in this paper prove that the Viking sand was deposited as a hydroplastic sediment. Deposition and deformation of the beds showing slump structure and convolute bedding must have happened in a matter of hours. Small depressions in the bottom of the sea were filled by crossbedded sands or only the foreset beds, and often the top of these sands was eroded immediately after deposition. To anybody who has attempted to correlate the individual Bow Island sands over a large area, it must be obvious that these sands are not continuous but strongly lensing. The production history of the Bow Island and the Viking confirms this picture. The frequent occurrence of pebble beds containing pebbles up to 1 inch in diameter is another feature not satisfactorily explained by the sand bar concept.

Shrock (1948) describes in detail the micro-structures mentioned in this paper and quotes explanations by both Hahn and Miller. Hahn ascribed the deformations to subaqueous gliding, presupposing that the sediment was at the subaqueous surface when it was deformed and that the deformation, therefore, was penecontemporaneous. Miller ascribes the deformation to slight tectonic differential slipping within the mass as a whole, during regional faulting. His explanation is, that the deformation was much later than deposition. Neither explanation connects the deformations with the transportation of material.

Kuenen (1950), however, offers an explanation of contemporaneous deformation directly connected with the transporting mechanism. Passega (1954) and Beach (1955, 1956) applied Kuenen's theories to the deposition of the Newcastle sand and the Viking respectively. These authors conclude that the Viking and its equivalents must have been deposited by high density, low velocity currents, or turbidity currents. For a detailed description of the mechanism of turbidity currents, the reader is referred to the above quoted publications. Strong objections against Beach's paper were raised by DeWiel (1956), who failed to find satisfactory correlations between conditions in Viking time and the continental slope on which the Grand Banks slide gathered considerable momentum before the turbidity current took over as transporting agent. The Grand Banks is the classical example of recent turbidity currents. It should be pointed out that the term "turbidity current" covers a considerable number of varied phenomena and that our knowledge today about this transporting mechanism is in its infancy.

The writer agrees with Gammell (1955) that the Viking is probably the result of a "momentary acceleration in the degradation of the highland to the southwest," and was not affected by any change in sea level. Increased elevations of the highland may have provided slopes steep enough to start a landslide, which, when submerged, was converted into a turbidity current. deWit (personal communication) suggested that the supply of material may have come from slides from a water-saturated steep coast. This type of slide has been observed in some of the dykes in Holland. The slides start on a small scale and progressively increase in size as material is eaten away from the coastline. A similar process on a larger scale may have taken place along the coast of the lower Colorado sea. Admittedly some of the characteristics of turbidity currents as quoted by Kuenen, specifically graded bedding, have not been found in the Viking. Kuenen has pointed out that we will have to review our interpretation of some types of deposits; specifically that some features previously considered to be proof of a littoral environment may be due to turbidity currents.

Economic Geology

No major Viking fields occur in the area under discussion, but a regional survey of productive porous trends was made. Figure 2 is based on all drillstem tests conducted in the Viking and Bow Island and has been supplemented with microlog information. Trends were drawn showing fluid recoveries on drillstem tests.

A comparison of this map (Fig. 2) with the isopach map top Devonian to top Blairmore (Fig. 6) reveals some striking connections. The porous trends in the Viking form a pattern similar to that of the isopachs. It seems that the main porous trends coincide with the wider spacing of the isopachs. Renaud (oral communication) made a similar observation when studying the Provost gas field, and concluded that flattening of the sea bottom had caused the accumulation of sand bars. The writer's conclusion is similar to that of Renaud with the modification that the turbidity currents slowed down over the flat parts of the sea bottom and lost the coarser particles suspended in the current.

Conclusion

Reviewing the various features described in this paper, we have the following picture: a well sorted sand with an extremely wide distribution, strongly lensing, containing minor quantities of conglomerate, and local accumulations of medium and coarse-grained sand. Throughout the area these sands show evidence of contemporaneous hydroplastic deformation.

Much work will have to be done before all arguments over the nature of the Viking sand can be settled. The writer is convinced that the mechanism of deposition, distribution, porosity, and therefore, the location of still unknown oil and gas accumulations are closely related to the detailed structures within the Viking sand. An examination of these structures is a most essential part of any study of the Viking.

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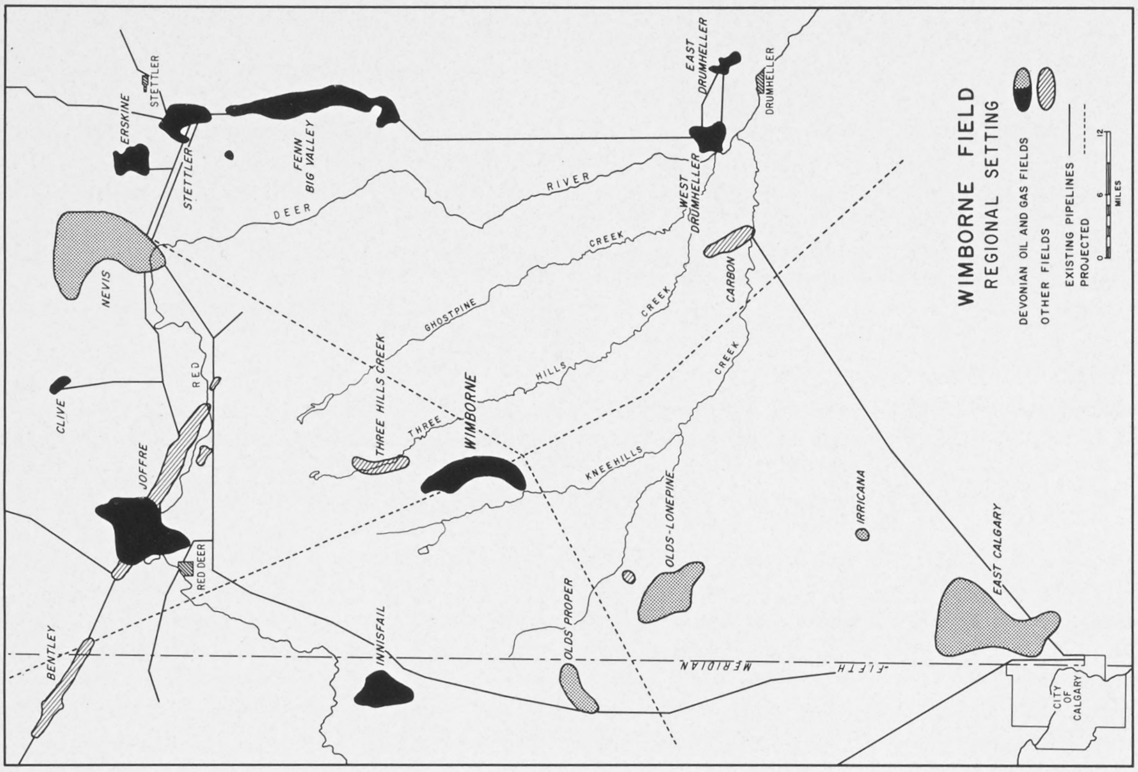

FIGURE 1

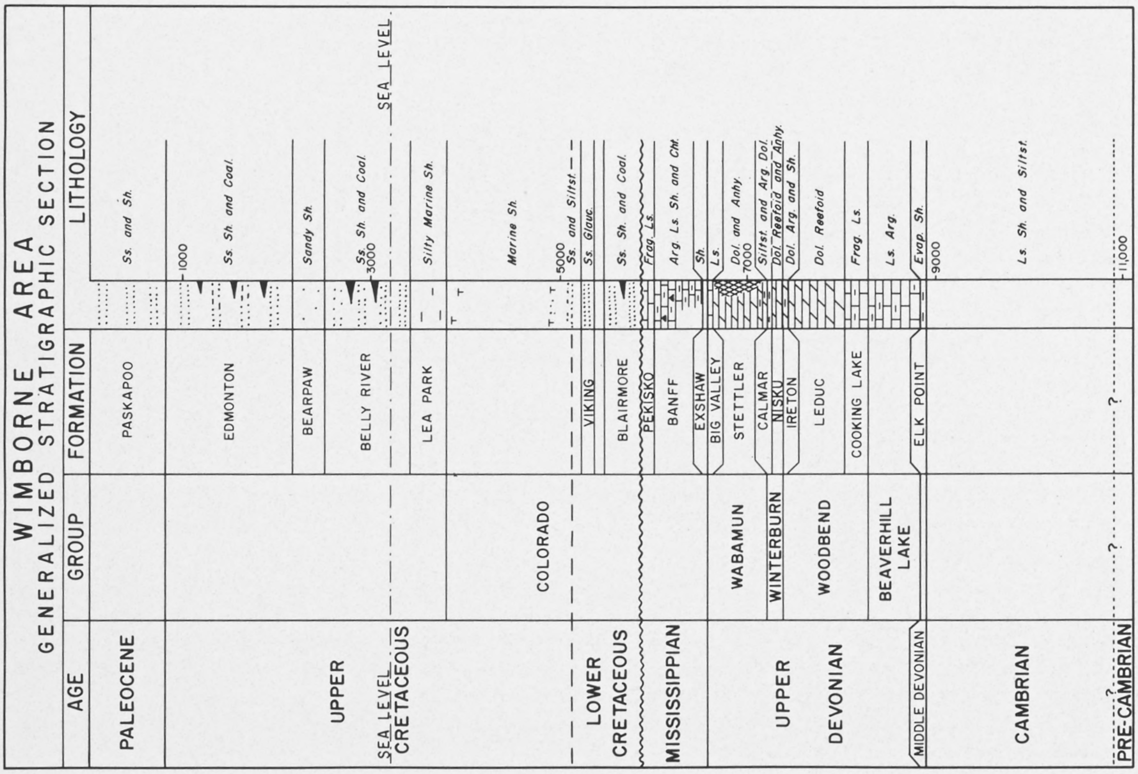

FIGURE 2

WIMBORNE OIL AND GAS FIELD, ALBERTA[1]

P. F. BRENNAN AND A. S. WARDEN [2]

Abstract

Discovered in 1954, Wimborne oil and gas field lies in southwestern Alberta, fifty miles northeast of the city of Calgary. The main oil and gas accumulation occurs in a dolomitized reef of Devonian Leduc age, with a secondary accumulation occurring at a higher elevation in the biostromal development in the Nisku formation of the Devonian Winterburn group. Nineteen wells have been drilled to the Leduc reef in the field area, of which thirteen are on steady production. No production is presently being taken from the Nisku.

Introduction

The Wimborne field is located in southwestern Alberta, some fifty miles northeast of the city of Calgary and twenty-five miles south-southeast of Red Deer. The producing area occupies a region of moderately-dissected, rolling farmland, draining southeast into the Red Deer River by way of the Three Hills and Kneehills Creeks. Ready access to the field is provided by all weather roads from nearby centres.

Regional Setting

The Wimborne field lies in a portion of the Alberta syncline characterized by a progressive increase in the west-southwesterly regional dip. The principal oil and gas accumulation occurs along the eastern edge of a dolomitized biohermal reef of Devonian Leduc age. The bioherm containing the accumulation lies on the eastern, up-dip, margin of a major reef-chain, which appears to trend north-northeast to south-southwest through the Devonian 'Green Shale' Basin.

A second accumulation of oil and gas occurs at Wimborne in the biostromal development of the Nisku formation of the Devonian Winterburn group, overlying the Ireton shale which caps the Leduc reef reservoir. This accumulation occurs in a development of porous Nisku where it drapes over the steep eastern edge of the biohern. In addition to the Leduc and Nisku accumulations discussed, shows of gas and oil have been obtained from Mississippian Pekisko carbonates and Cretaceous sands higher in the geological section. The regional setting of Wimborne field is shown in generalized form in the index map comprising Figure 1.

History of Discovery and Development

The existence of a Devonian Leduc formation bioherm in the Wimborne area of southern Alberta was demonstrated in 1951 by the wildcat well, Socony-Amerada-Gulf Wimborne No. 1 (Lsd. 15, Sec. 11, Twp. 34, Rge. 26, W4M). This well, drilled to evaluate a seismic anomaly in a portion of the Alberta basin known to have been favourable for biohermal growth during Leduc time, penetrated 415 feet of variably porous reef. The reef section proved water-bearing on test: however, the presence of oil stain in the uppermost 230 feet, plus the prolific nature of Leduc production elsewhere in the basin, focussed considerable exploration effort on the area. Intensified geophysical and subsurface geologic studies and structure drill work, with concomitant additional wildcat drilling resulted in the discovery of oil and gas in the reef at Seaboard Banff Wimborne 7-9, (Lsd. 7, Sec. 9, Twp. 34, Rge. 26, W4M). This well was completed in September 1954, producing light gravity oil from a 13 foot oil pay zone below gas cap. Production difficulties arose early in the life of the well, and it was subsequently suspended owing to exessive gas-oil ratios. Subsequent wildcat and development drilling, indicated a maximum reef thickness of 560 feet with a total gross hydrocarbon column of 102 feet developed in the present crestal area.

Although the Wimborne field was found during the phenomenal period of reef exploration sparked by the discovery of Leduc, its development has been infinitely slower than that of most other reef fields. The reason for this laggard development lies in the presence of an extremely thin oil column overlain by a thick gas cap and underlain by a porous water zone. This situation has resulted in very tight economics in the production of oil, together with mechanical difficulties in the effecting of water free, low-gas-oil-ratio completions.

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2 Geologists, Mobil Oil of Canada, Ltd.

To date, a total of nineteen wells has been drilled to the Leduc reservoir in the Wimborne field: of these, fifteen are considered capable of commercial production of oil or gas. Present daily oil production from the Leduc reservoir in the field is some 500 barrels, with production reported from 13 wells during the month of December 1958. During this month, the field also produced 38,470 Mcf of gas and 1,090 barrels of salt water. In its present state of development, the Leduc reef pool at Wimborne includes an area of some 19,000 surface acres within the zero pay isopachyte.

The Nisku reservoir at Wimborne, which had yielded shows in early wildcats, gave up its first commercial oil production in November 1953. The wildcat well, Socony Wimborne 14-11 (Lsd. 11, Sec. 14, Twp. 34, Rge. 26, W4M), on the eastern edge of the field, found the Leduc reservoir water-bearing but was completed as an oil well from nine feet of net oil pay in the Nisku biostrome. Flush production from the well was high: however, rapid water encroachment occurred, causing early suspension of the well.

Since the drilling of Wimborne 14-11, Nisku oil and gas pay has been found in nine wells drilled to the Leduc reservoir along the eastern edge and present crestal area of the reef. The probable eventual size of the Nisku accumulation is conjectural, since systematic development of this reservoir has not yet been undertaken, and no production is being taken at present from the zone.

Stratigraphy

Down to and including the Devonian, the Wimborne geological succession is generally similar to that present in other reef development areas of southern Alberta. Lithologies and thicknesses of older formations have been interpreted from regional considerations and data from an abandoned Cambrian test drilled southeast of the reef area. The sedimentary column at Wimborne is estimated to be 11,000 feet thick, comprising 2,000 feet of Cambrian, 40 feet of Middle Devonian, 2,200 feet of Upper Devonian, 670 feet of Mississippian, 5,100 feet of Cretaceous and up to 1,000 feet of Tertiary and Recent deposits.

Cambrian sediments present are not formationally differentiated: they comprise varicoloured shales and siltstones with dense limestone interbeds. The Middle Devonian is represented by a thin section of evaporitic shale of the Elk Point group.

The Upper Devonian is represented by the Beaverhill Lake group, the Woodbend group (Cooking Lake, Duvernay, Leduc and Ireton formations), the Winterburn group (Nisku, Calmar and Graminia formations) and the Wabamun group (Stettler and Big Valley formations). The Beaverhill Lake group approximates 500 feet in thickness and consists in ascending order of an argillaceous limestone unit, a thick series of fragmental, fossiliferous, sporadically-porous limestones and an upper dense argillaceous limestone and shale unit. The Cooking Lake formation is some 250 feet thick and consists mainly of dark-brown, fragmental, fossiliferous, occasionally dolomitic limestones and minor anhydrite. An argillaceous limestone band in the lower part of the formation appears to be correlative with a marker in the Stettler area thirty-five miles to the northeast (Andrichuk 1958). Above the Cooking Lake occurs a 200 foot section of Duvernay, consisting of dense fossiliferous limestones and grey-brown, partially-bituminous shales, the latter being principally confined to the upper part of the section.

The Leduc formation in the field area comprises up to 560 feet of massive, drusy, reefoid dolomite. The lower part, ranging in thickness from 400 feet on the reef flank to 150 feet in the central part of the reef, consists of dark-brown, crystalline dolomites of bituminous aspect, and appears to represent the "Brown Reef" of Andrichuk and Wonfor (1954). This section of the reef is considered correlative in part with the Duvernay, and possibly represents the effect of a restricted inter-reef environment on early reef growth. The upper portion of the reef, reaching a thickness of over 400 feet in the central area, consists of grey to buff, fragmental, porous dolomite, with lenses and thin interbeds of white anhydrite.

Dolomitization has obliterated most original organic remains in the Leduc section, although vugs occur in shapes suggesting an organic origin. Fracturing is common throughout, occasionally in sufficient intensity to impart a brecciated appearance to the rock. The effects of this fracturing on the producing characteristics of the reef are not known, but could be considerable. Porosity and permeability vary greatly throughout the section, with the uppermost few feet of reef rock commonly being infilled and tight. The Ireton section overlying the Leduc varies in thickness from 30 to 100 feet in the field area and consists of dense, grey-buff, dolomite with shale interbeds. The formation thickens rapidly off the edge of the reef, with up to 300 feet of grey-brown, argillaceous limestone and grey calcareous shale developing below the dolomite present over the reef area.

The Nisku formation at Wimborne varies in thickness from 75 feet over the reef to 175 feet off the flank. Three units are recognizable, comprising a basal unit of dark-brown, anhydritic dolomite, which is generally lacking is effective porosity; a middle unit of light-grey, partially reefoid, porous dolomite, and an upper unit of dense dolomite with shale interbeds and abundant anhydrite. The middle unit is the principal Nisku reservoir along the eastern edge of the underlying reef: west of the present reef crest, effective porosity in this section is largely obliterated. Fracturing is common in the Nisku where its dip is reversed off the east flank of the reef, and this undoubtedly affects the productive characteristics of the formation. A ten foot thick section of siltstone, sandstone and dolomite above the Nisku represents the Calmar formation; the overlying Graminia being difficult to distinguish from the basal beds of the Wabamun group.

The Wabamun group varies in thickness from 640 feet over the reef to 700 feet off the flank, and can be broken down into a lower, evaporitic, Stettler formation and an upper, carbonate, Big Valley formation, as in the Stettler area to the northeast. (Lockwood and Erdman 1951, Andrichuk and Wonfor 1954).

The Mississippian of the Wimborne area averages 670 feet in thickness and comprises the Exshaw, Banff and Pekisko formations in ascending order. The Exshaw of the field area consists of up to 15 feet of black shale, and is overlain by 550 feet of dense argillaceous limestones, fragmental limestones, cherts and calcareous shales of the Banff formation. The overlying Pekisko varies greatly in thickness owing to erosion of its upper part and markedly diachronic relationships, with the Banff, and has as its dominant lithology a white to buff, fragmental, often chalky, limestone.

A normal sequence of Cretaceous shales and sands overlies the Mississippian erosional surface, the sands being generally infilled by clay minerals and lacking in reservoir potential. Up to 1,000 feet of Tertiary and Recent sediments occur above the Cretaceous, exhibiting sedimentary aspects typical of this portion of the Alberta basin. The overall succession of the Wimborne area is shown in tabular form in Figure 2.

Structure and Control of Accumulation

Regional dip in the Wimborne area is to the west-southwest, with a progressive increase in structural gradient occurring as the deeper portion of the Alberta syncline is entered.

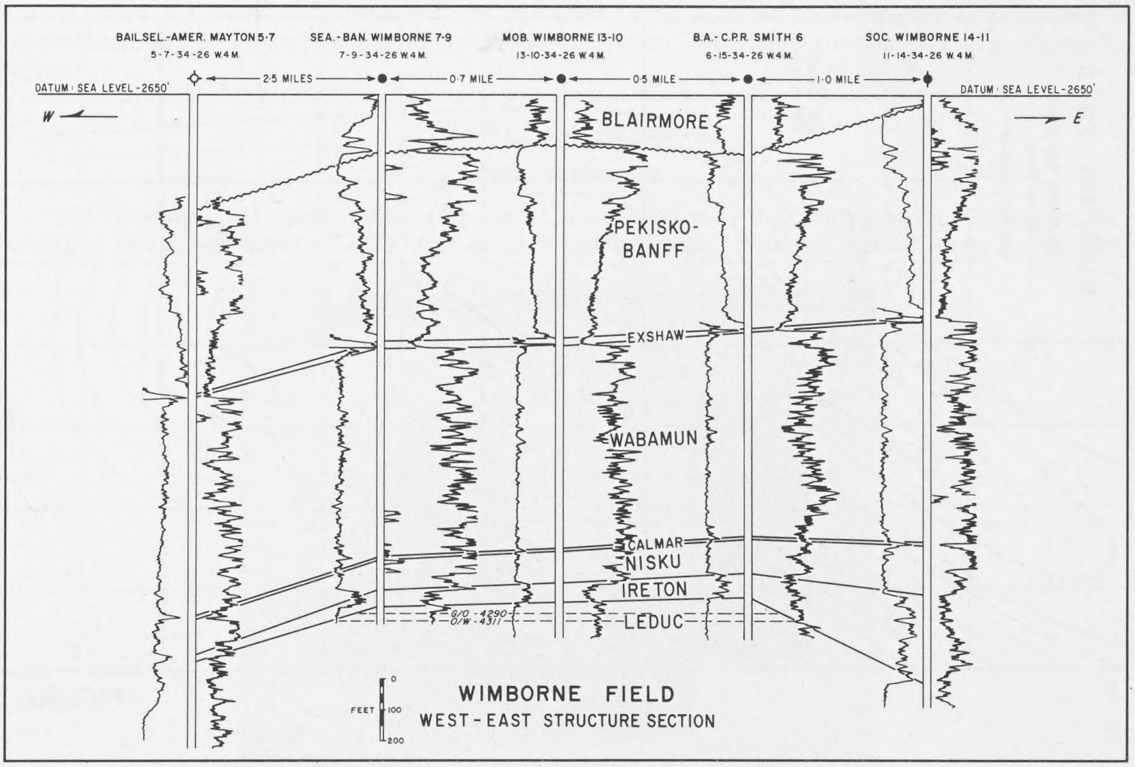

FIGURE 3

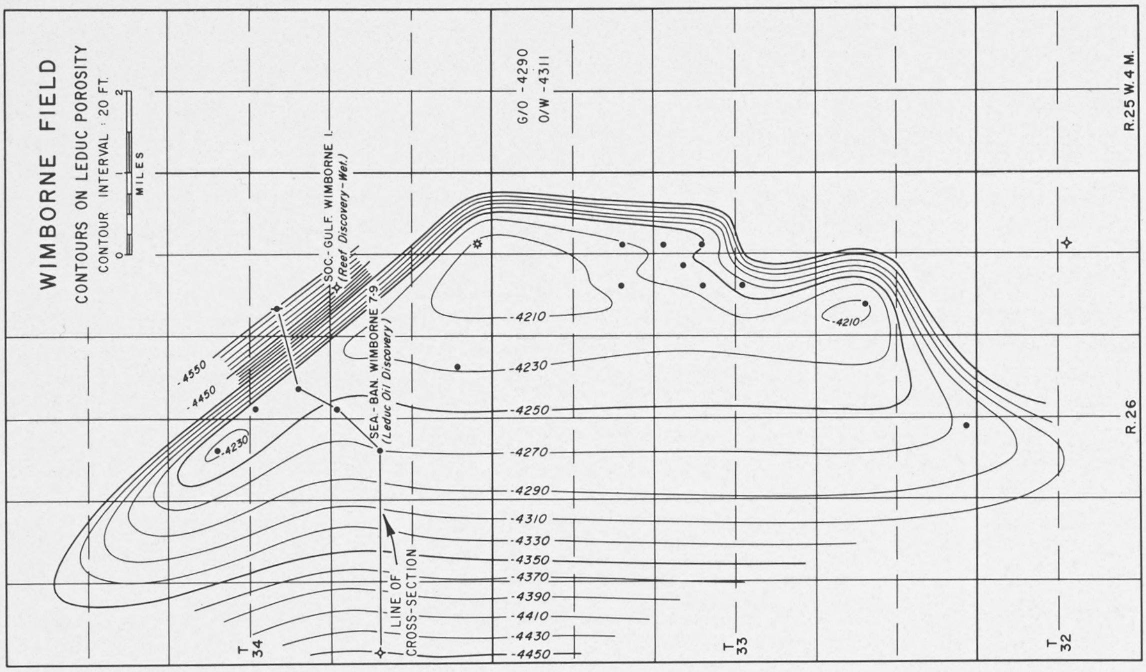

FIGURE 4

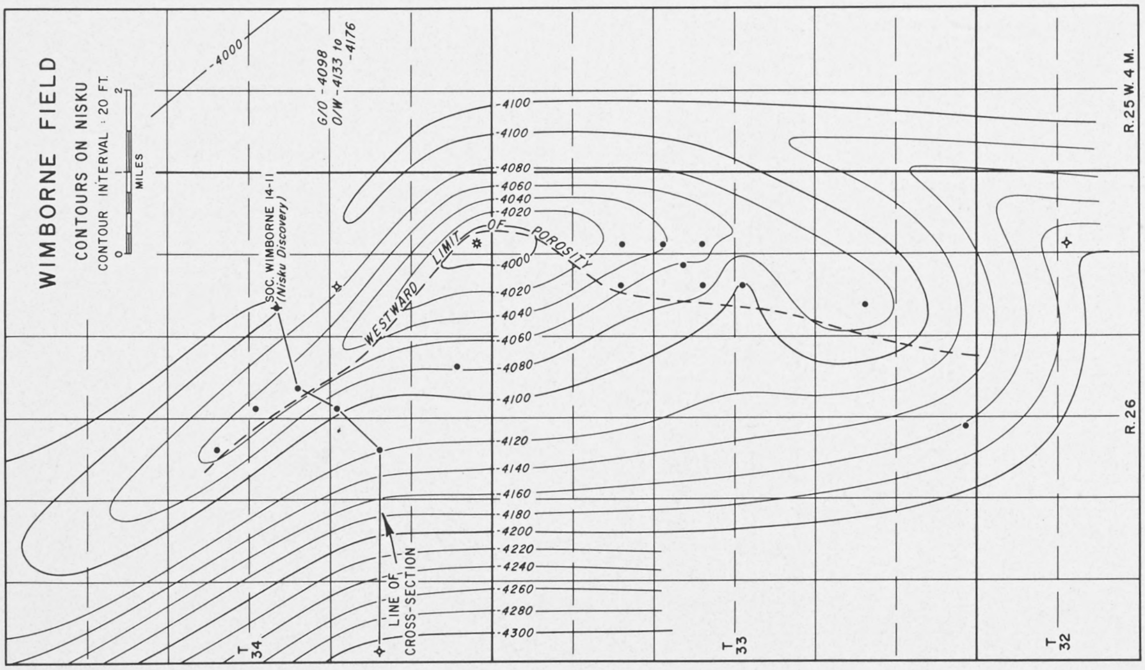

FIGURE 5

Immediately east of the field area, the average dip is 30 feet per mile on Lower Cretaceous and 40 feet per mile on Upper Devonian horizons. Five miles west of the field area, these values have increased to 50 and 65 feet per mile respectively.

The Wimborne Leduc bioherm has been tilted out of its original position of growth by the progressive westward increase in subsidence of the Alberta syncline. Tilting appears to have proceeded slowly following its initiation in later Palaeozoic time and to have proceeded at a more accelerated pace during the Mesozoic. Hydrocarbons migrating into and up through the reef finally came to rest in a crescentic lobe along the eastern, up-dip, edge of the bioherm, beneath the overlying impermeable Ireton beds, to form the existing Leduc accumulation. This accumulation is not located at the apparent high axis of reef growth, which, from considerations of Ireton thicknesses, would seem to lie four miles west of the present reef crest.

As in other areas of reef development, structure in formations overlying the Leduc appears to be largely a function of compaction and draping to form supratenuous folds. Structural relief resulting from this process decreases rapidly in magnitude upwards in the section; thus, closure on the Ireton top is 140 feet, on the Wabamun top 40 feet and on Cretaceous horizons, negligible. These figures compare with those released for the Innisfail field by White and Charles (1958).

Average gas-oil and oil-water interfaces of -4290 feet and -4311 feet respectively are assigned to the Wimborne Leduc reservoir. Considerable variation of both is noticeable in some parts of the field; in addition, an oil-water transition zone of minor thickness is observed locally. Figure 3 represents a west-east structure-section through the field, while Figure 4 shows structural configuration on top of the Leduc reservoir, illustrating features discussed above.

The Nisku accumulation at Wimborne occurs in a combination structural-stratigraphic trap caused by reversal of formational dip over the steep eastern edge of the Leduc reef in conjunction with a north-south trending porosity barrier. Structural closure on the Nisku where it drapes over the reef edge is 118 feet: considerable fracturing attends this flexure and undoubtedly affects the distribution of porosity and permeability in the reservoir. The porosity barrier forming the updip seal lies just west of the present reef crest and appears to be a function of thinning of the reservoir unit, infilling of porosity by anhydrite, and decrease in intensity of fracturing. Relatively little is known about the extent of the Nisku accumulation, owing to lack of systematic development and of production history for wells penetrating the reservoir. Existing data indicate an average gas-oil interface of -4098 feet with oil-water interfaces of -4176 feet and -4136 feet respectively prevailing in the northern and southern portions of the productive area. Structure on the Nisku is shown in Figure 5.

Pay Data and Reserves

LEDUC RESERVOIR

The reservoir rock of the Wimborne Leduc accumulation is a dolomitized reef limestone, occurring at an average depth of 7,500 feet in the main field area. Both gas and oil zones are present,

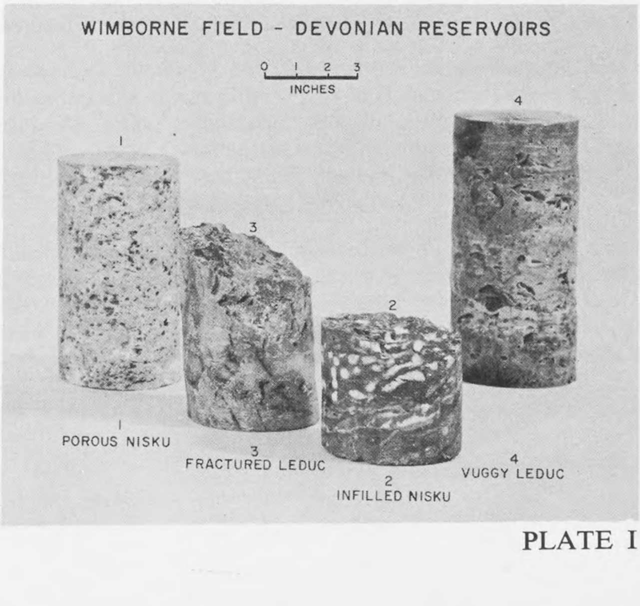

PLATE I

with average net pays being 39 feet in the gas cap and 21 feet in the oil zone. Porosity and permeability vary widely throughout the productive section, the average porosity being 6.6 percent and the average horizontal permeability 450 millidarcies.

The original gas in place is estimated at 267 MMMcf and the original oil at 90 million stock tank barrels. To the end of December 1958, the field had produced cumulative totals of 708,522 Mcf of gas, 274,234 barrels of oil and 10,659 barrels of salt water. The gas present is wet and sour, with appreciable content of hydrogen sulphide and nitrogen. The oil produced is also sour and averages 41° API gravity.

NISKU RESERVOIR

The reservoir rock of the productive Nisku is a dolomitized limestone, exhibiting vuggy and fracture porosity, and occurring at an average depth of 7,300 feet in the productive area. Average net gas pay in the Nisku is 10 feet and average net oil pay, 9 feet. Porosity averages 5 percent over the reservoir section and permeability 19 millidarcies. The gas present is sour, with appreciable content of hydrogen sulphide. No commercial production is presently being taken from the Nisku reservoir; however, oil recovered on drillstem test is sour and grades 40° API gravity.

Examples of typical Devonian reservoir rocks from Wimborne field are shown in Plate I.

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DRUMHELLER OIL FIELDS, ALBERTA

M. R. ROOP [1]

Abstract

The Nisku, Leduc and Basal Quartz are the producing zones in the West Drumheller and Drumheller oil fields which were discovered between 1950 and 1952. The Nisku formation of the Upper Devonian is the primary reservoir. Production is also obtained from the Leduc reef at West Drumheller, and from the Lower Cretaceous Basal Quartz sandstone in Drumheller. The Nisku consists of two units; an upper unit of dense, evaporitic dolomite and anhydrite, and a lower unit of porous crystalline dolomite, which is the reservoir rock. The trap at West Drumheller is due to reef 'build-up; at Drumheller it is stratigraphic. Reservoir and development data are presented in the text.

Introduction

Drumheller and West Drumheller, the two oil fields in the Drumheller area, are three miles northeast and six miles north-northwest of the city of Drumheller, respectively. The fields are approximately 100 miles northeast of Calgary and 35 miles south of the Stettler-Fenn-Big Valley Devonian oil fields. Wells of the Drumheller fields are located on the upper plains level at a general elevation of 2,700 feet, except for several wells in the west part of the West Drumheller field, which lie at an elevation of 2,300 feet in the deeply incised valley of the Red Deer River (Fig. 1).

Oil was discovered in the Drumheller field on November 26, 1950 at Naco Drumheller 2, (Lsd. 14, Sec. 36, Twp. 29, Rge. 20, W4M) wildcat. On a drill-stem test of the Basal Quartz, 1,570 feet of oil was recovered, and the well was completed in this zone after being plugged back from the Mississippian. Nisku oil was found in August, 1951 at Dome-Naco Drumheller 30-14 (Lsd. 14, Sec. 30, Twp. 29, Rge. 19, W4M), when, during a test of the Nisku over the interval 5,385 to 5,405 feet, 35 degree A.P.I. oil flowed to the surface. Mazal Drumheller 1 (Lsd. 12, Sec. 36, Twp. 29, Rge. 21, W4M), is the discovery well for the West Drumheller field. The well was completed on September 17, 1952 as a Nisku oil well with an Initial Potential of 1,200 B.O.P.D. Leduc production followed in September, 1953, when, on a test of this formation at British American West Drumheller 12-1 (Lsd. 12, Sec. 1, Twp. 30, Rge. 21, W4M), oil flowed to the surface at an estimated rate of 89 B.O.P.H. The Glauconite sandstone is also prospective throughout the general area; two suspended oil and gas wells from this sandstone lie midway between the two fields.

Geology

Stratigraphy

Figure 2, a composite log of a typical well in the Drumheller area, shows the lithology and log characteristics of the section from the Graminia and Calmar into the Leduc. The markers correlated in this figure are readily defined and are those that were used during the development of the fields. Correlation of these markers with the Devonian classification proposed by Belyea and McLaren (1957) is shown. Their classification demonstrates the relationship of Devonian rocks of the report area with those of the outcrop belt of our Field Conference Area.

The stratigraphic section overlying the Winterburn is approximately 5,450 feet thick. The "Mesozoics" are represented by approximately 4,100 feet of Upper Cretaceous and 500 feet of Lower Cretaceous sediments. The Palaeozoic section comprises about 350 feet of Mississippian (Banff) and 500 feet of Devonian (Wabamun). A discussion of post-Winterburn stratigraphy has been previously discussed for typical central Plains wells in previous papers by Lockwood and Erdman, (1951), and Wonfor and Andrichuk, (1956).

The Nisku formation is overlain by the silts of the Graminia and Calmar formations. These silts consist of pale green to grey, clear quartz grains cemented in dolomite. The silt interval varies in thickness from 10 to 50 feet. Locally, especially near the reef edge, there are as many as five silt bands separated by thin bands of white to ivory, dense, medium-crystalline dolomite and anhydrite. The Nisku ranges in thickness from approximately 100 feet over the West Drumheller field to more than 230 feet off structure. It is divisible into two units, an upper unit of dense evaporitic dolomite and anhydrite and a lower unit of porous dolomite. The lower unit is the reservoir rock of the Nisku.

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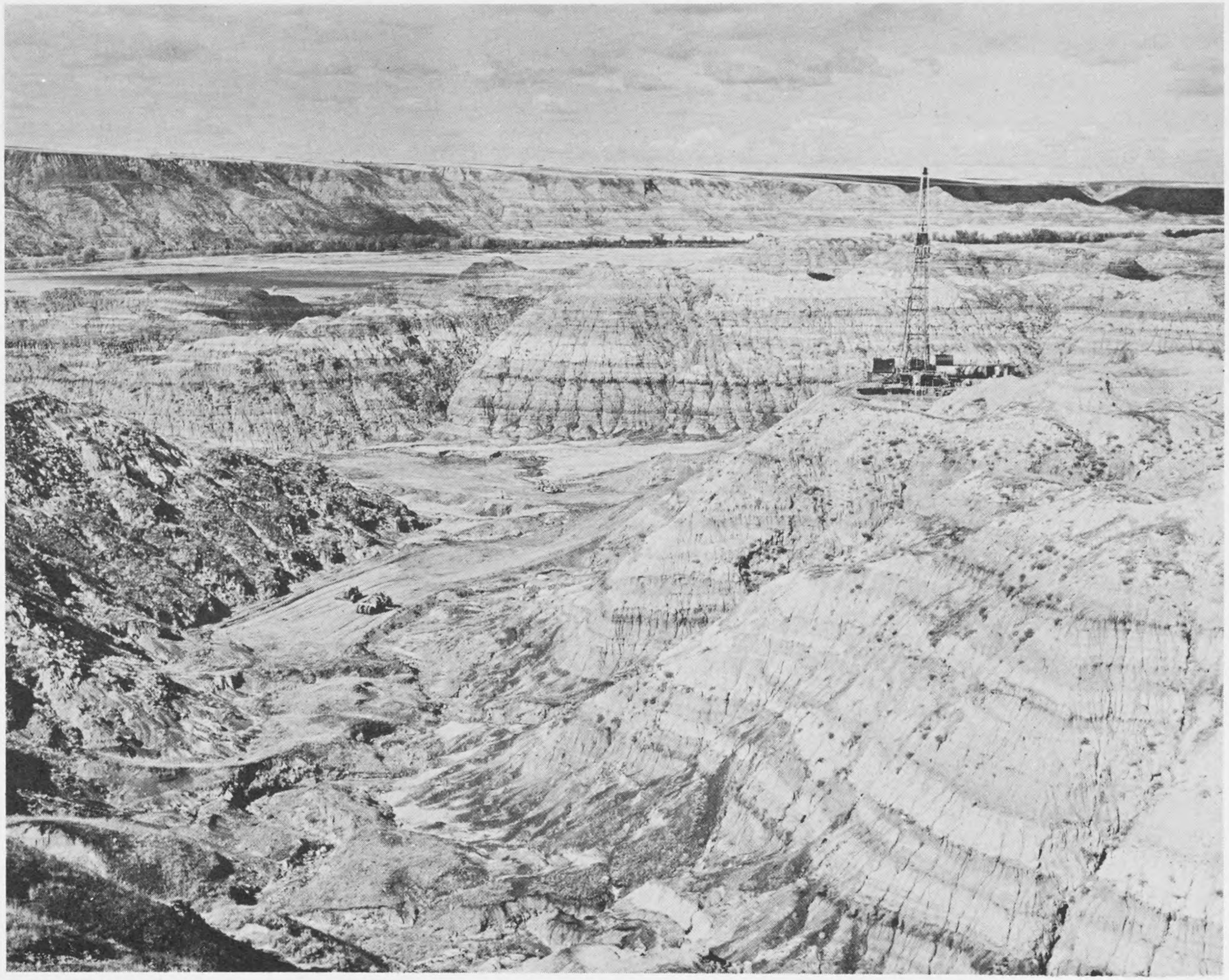


FIGURE 1

View looking northwest across the westernmost well locations of the West Drumheller field and the north-south reach of the Red Deer River. Orkney Hills viewpoint is located at plains level on the west bank of Red Deer River directly opposite well-site. The drilling well is British American West Drumheller 9-3 (Lsd. 9, Sec. 3, Twp. 30, Rge. 21, W4M) completed on November 17, 1955 as a Nisku oil well.

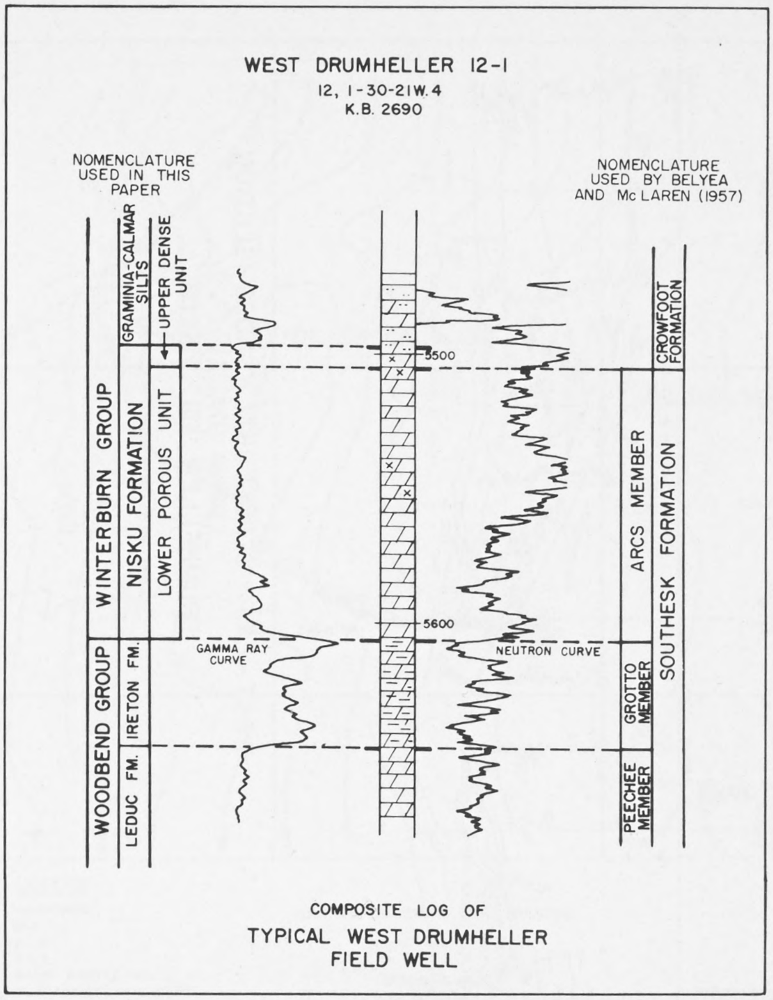


FIGURE 2

The upper unit consists of dense, tan, fine-crystalline dolomite interbedded with variable amounts of anhydrite. The unit thickens eastward from the West Drumheller field where it ranges from zero to twenty feet thick. In the Drumheller field it is 70 feet thick, and at El Centro et al Drumheller 8-20 (Lsd. 8, Sec. 20, Twp. 29, Rge. 19, W4M), directly east, it is 170 feet thick. Thickness variations of the upper unit in the West Drumheller field may be due to depositional thinning over the underlying high reef mass.

The lower porous unit is a tan to cream, fine to coarse-crystalline dolomite with local bands of brown granular dolomite and minor anhydrite. The erratic distribution of the bedded anhydrite indicates small lenses rather than widespread deposits. Porosity in the reservoir rock is primarily vugular and intercrystalline. Minor oblique fracturers are also present. The vugs are solution and fossil in origin and range from pinpoint to one inch in diameter. Secondary anhydrite fills much of the original porosity. The Nisku porosity averages 4.7 per cent in the West Drumheller field, and 7.6 per cent in the Drumheller field. Maximum porosity is about 12 per cent. The lower unit becomes argillaceous towards the base and the contact with the underlying Ireton formation of the Woodbend group is gradational rather than abrupt.

The Ireton formation is predominately a grey-green, argillaceous dolomite which grades to a dolomitic shale. The typical "Green Shale" of the formation is not present in the fields. The average thickness of the Ireton over the fields is 50 feet. Its contact with the underlying Leduc formation is abrupt.

The Leduc consists of ivory to tan, medium to coarse-crystalline dolomite. Porosity is intercrystalline, vugular and fracture with the intercrystalline and vug porosity providing more than 90 per cent of the effective porosity.

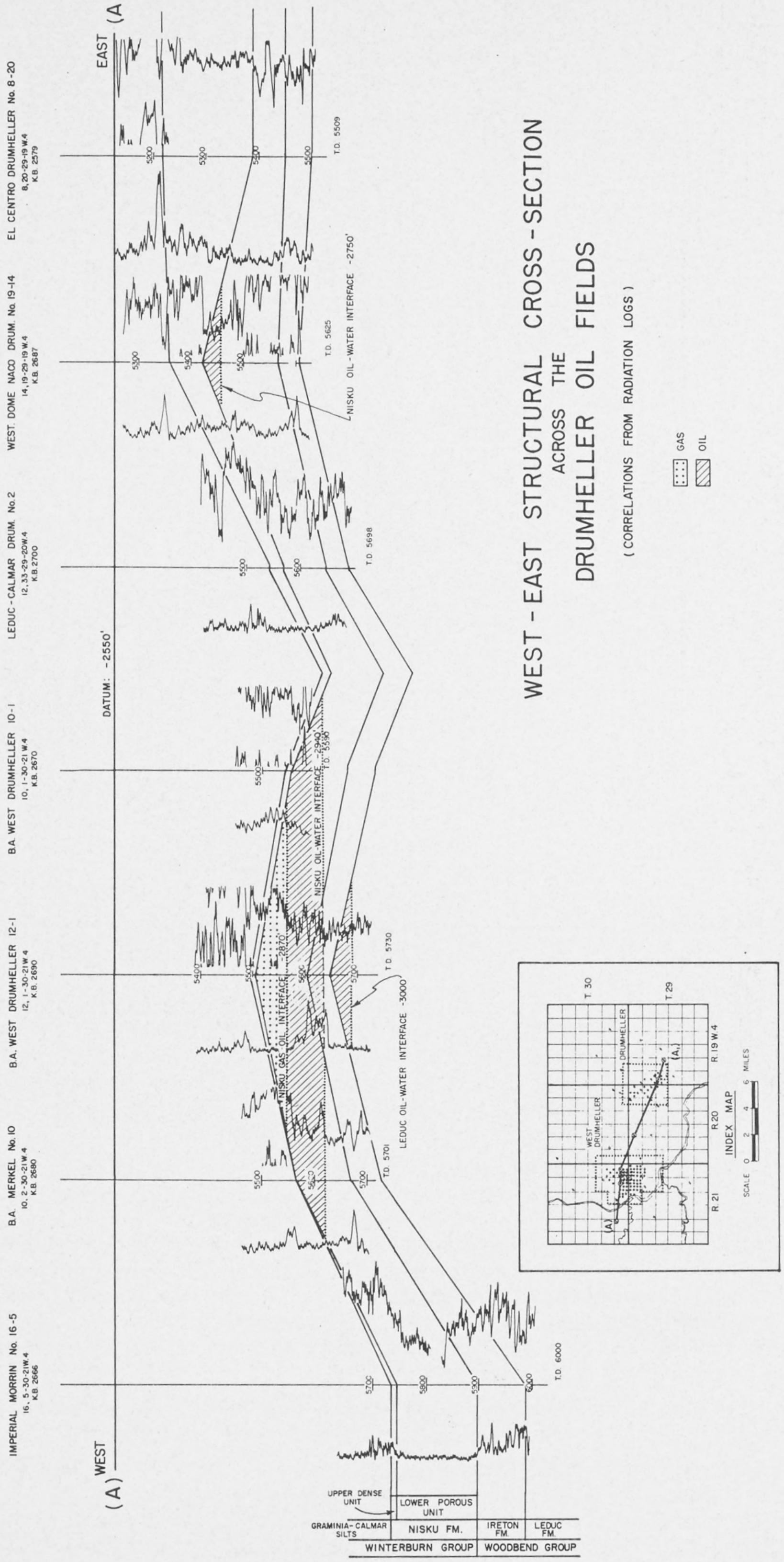

WEST - EAST STRUCTURAL CROSS - SECTION
ACROSS THE
DRUMHELLER OIL FIELDS
(CORRELATIONS FROM RADIATION LOGS)
GAS
OIL
(A) WEST
EAST (A1)
DATUM: -2550'
IMPERIAL MORRIN No. 16-5
16, 5-30-21 W.4
K.B. 2666
B.A. MERKEL No. 10
10, 2-30-21 W.4
K.B. 2680
B.A. WEST DRUMHELLER 12-1
12, 1-30-21 W.4
K.B. 2690
B.A. WEST DRUMHELLER 10-1
10, 1-30-21 W.4
K.B. 2670
LEDUC-CALMAR DRUM. No. 2
12, 33-29-20 W.4
K.B. 2700
WEST DOME NACO DRUM. No. 19-14
14, 19-29-19 W.4
K.B. 2687
EL CENTRO DRUMHELLER No. 8-20
8, 20-29-19 W.4
K.B. 2579
T.D. 6000
T.D. 5701
T.D. 5730
T.D. 5590
T.D. 5698
T.D. 5625
T.D. 5509
NISKU GAS-OIL INTERFACE -2870'
NISKU OIL-WATER INTERFACE -2940'
LEDUC OIL-WATER INTERFACE -3000'
NISKU OIL-WATER INTERFACE -2750'
UPPER DENSE UNIT
LOWER POROUS UNIT
GRAMINIA-CALMAR SILTS
NISKU FM.
IRETON FM.
LEDUC FM.
WINTERBURN GROUP
WOODBEND GROUP
INDEX MAP
T. 30
T. 29
R. 21
R. 20
R. 19 W.4
WEST DRUMHELLER
DRUMHELLER
SCALE 0 2 4 6 MILES

FIGURE 4

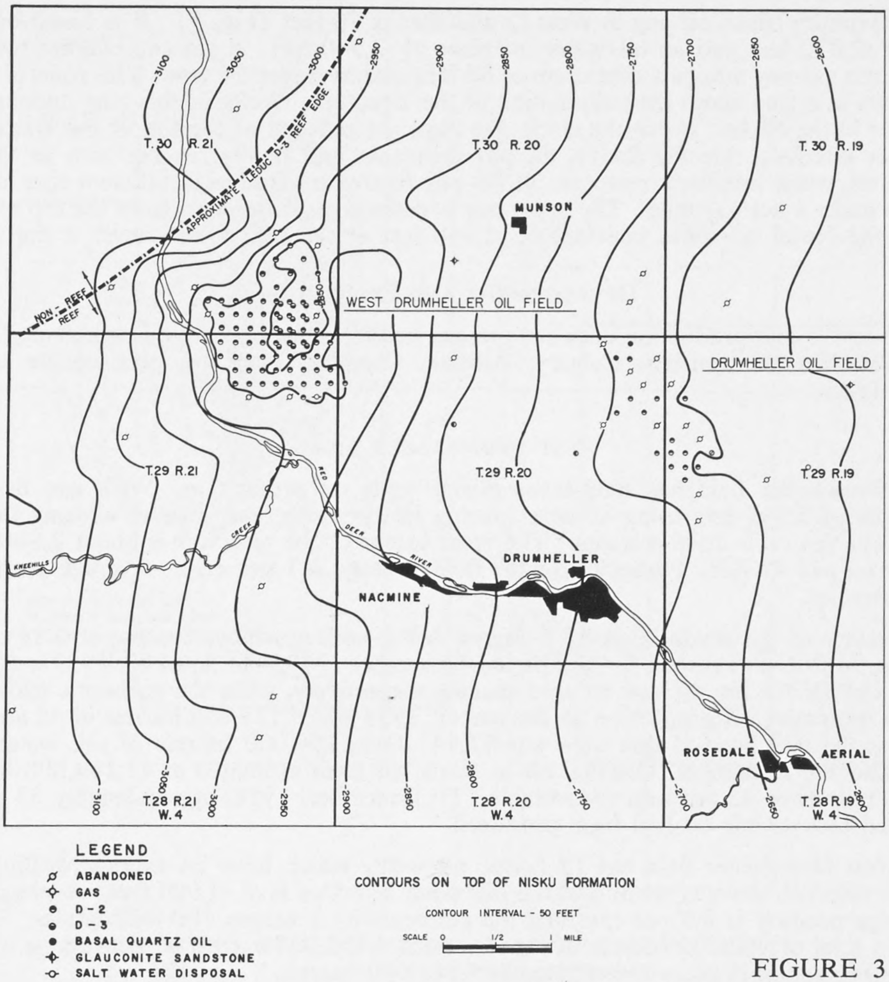


FIGURE 3

STRUCTURE AND RESERVOIR BOUNDARIES

Contours on top of the Nisku formation (Fig. 3) show these beds to strike north-south, and dip at approximately 50 feet per mile to the west. The map area is underlain by Leduc reef except in Township 30, Range 21, W4M., where the reef edge trends north-east through the township. The closure shown over the West Drumheller field results from draping of Nisku and Ireton sediments over the underlying Leduc reef build-up. A small west trending nose is present over the Drumheller field. No closure over this field is shown on the map, but closure is evident where a smaller contour interval is used.

Figure 4 is a west-east cross-section from Imperial Morrin 16-5 (Lsd. 16, Sec. 5, Twp. 30, Rge. 21, W4M), two miles west of the West Drumheller field, to El Centro et al Drumheller 8-20 (Lsd. 8, Sec. 20, Twp. 29, Rge. 19, W4M), directly east of the Drumheller field. The abrupt drop-off and thickening of the Ireton and Nisku formations suggest that the Imperial Morrin 16-5 well is near the reef edge. Over the West Drumheller field maximum closure above the oil/water interface on the Nisku is 133 feet and on the Leduc 45 feet. The Ireton is shown rising above the Nisku oil/water interface of -2,940 feet on the section at the British American West Drumheller 12-1 (Lsd. 12, Sec. 1, Twp. 30, Rge. 21, W4M) well. There the gross Nisku oil pay is reduced from 70 feet maximum, for the field, to 46 feet. The abrupt eastward thickening of the upper Nisku evaporite unit at the expense of the lower unit is clearly demonstrated. This facies attests to a different depositional environment than that near the reef-front. Figure 4 also demonstrates the types of trap in the Devonian in these fields. The West Drumheller field has resulted from a reef build-up in the Woodbend group, whereas the Drumheller Nisku field is stratigraphic. The three Basal Quartz wells also produce from a local stratigraphic trap.

The maximum Nisku oil pay in West Drumheller is 70 feet (Fig. 5). It is based on a gas/oil interface of -2,870 feet and an oil/water interface of -2,940 feet. A gas cap overlies the Nisku oil column. Gross gas pay attains a maximum of 60 feet and averages 34 feet. The zone of maximum oil pay occurs in a ring about the culmination of the structure. Wells in this ring encountered gas, oil and water in the Nisku. Inside the circle, the pays are reduced as the top of the Ireton is above the oil/water interface. On the flanks, the pay decreases and finally reaches zero as the porosity top and the oil/water interface converge. Gross pay figures are used as insufficient core analyses are available to make a net pay map. The gross pay is defined as the interval from the top of the Nisku porosity to the Nisku oil/water interface of -2,940 feet or the Ireton, whichever is the uppermost.

Development and Production

The reservoir and production data are summarized from the Reservoir Engineering Digest published by Brodylo Publications, Calgary, Alberta, Canada. They are pertinent to the end of December, 1958.

West Drumheller Field

West Drumheller field has sixty-seven Nisku wells on production. Wells are drilled to an average depth of 5,555 feet using 40-acre spacing in the south, and 80-acre spacing in the north (Fig. 3). The reservoir drive is water. The areal extent of the reservoir is about 3,800 acres and the average oil pay 49 feet. Porosities for the field average 4.7 per cent. Average permeability is 1,500 millidarcies.

The gravity of the crude oil is 41.7 degree A.P.I. with a sulphur content of 0.28 per cent by weight. The M.P.R. established for the period November 1, 1958 to April 30, 1959 is 65 B.O.P.D. and 115 B.O.P.D. for the 40 and 80 acre spacing respectively, while the economic allowable is 42 B.O.P.D. Cumulative oil production to December, 1958 was 6,123,859 barrels of oil and the price per barrel at the well head at that time was $2.54. Over 290,000 barrels of salt water had been reinjected into the formation. Original oil in place has been estimated at 41,144,000 barrels with 18,515,000 barrels or 45 per cent recoverable. To December, 1958, approximately 33 per cent of the estimated recoverable oil had been produced.

The West Drumheller field has 12 Leduc oil wells, which have an average drilling depth of 5,655. The reservoir drive is water and the oil/water interface is at -3,000 feet. Average pay is 24 feet. Average porosity is 8.9 per cent and the permeability averages 700 millidarcies. To December, 1958, a total of 902,179 barrels of the estimated 3,352,000 barrels of recoverable oil had been produced. Original oil in place is estimated at 8,381,000 barrels.

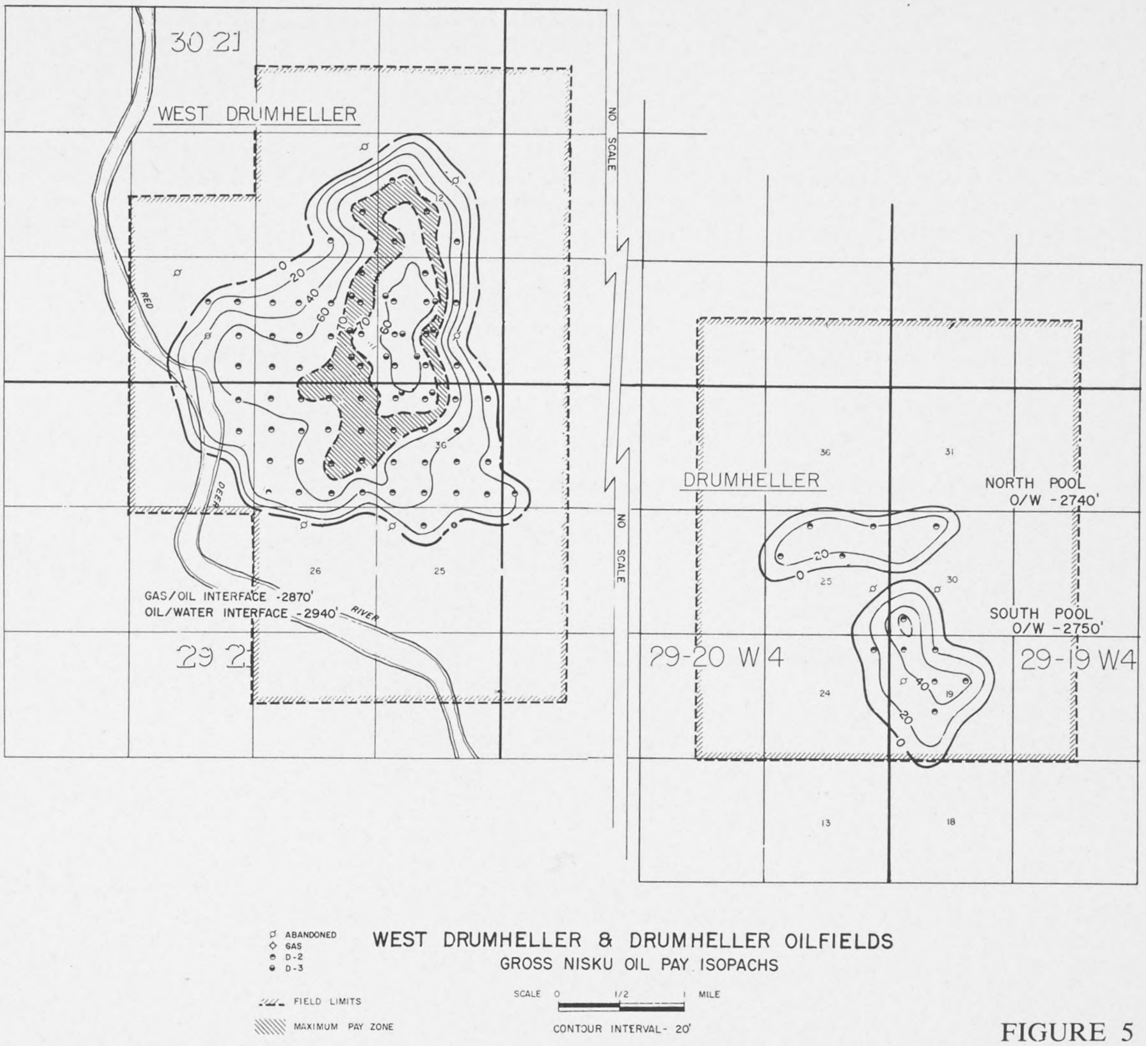
Drumheller Field

Two Nisku pools and a Basal Quartz pool are present in the Drumheller field (Fig. 5). The Nisku pools, here defined as the north pool and the south pool, have oil/water interfaces of -2,740 feet and -2,750 feet, and average pays are 17 and 22 feet respectively.

The Drumheller field has thirteen Nisku wells capable of production, eleven of which are on production. The field was developed on 40-acre spacing. Average drilling depth to the Nisku is 5,435 feet. The reservoir drive is water.

Average porosity is 7.6 per cent and the average permeability 700 millidarcies. The M.P.R. established for the period November 1, 1958 to April 30, 1959 is 75 B.O.P.D., while the economic allowable is 41 B.O.P.D. It is estimated the field contained 8,694,000 barrels of oil in place originally and that the original recoverable oil would be 3,478,000 barrels or 45 per cent. Of this, 1,708,457 barrels or approximately one-half of the recoverable oil had been produced to the end of December, 1958. The oil is 33.2 degree A.P.I. sour crude.

Three Lower Cretaceous Basal Quartz wells are also on production. The wells are drilled on 40-acre spacing and the average drilling depth is 4,450 feet. The oil/water interface is variable and the average pay is 15 feet. The gravity of the oil is 31.5 degree A.P.I. Average porosity for the sand is 20 per cent. Due to lack of core data no figure is available for the average permeability but it is estimated at approximately 100 millidarcies. Production is limited and, to December, 1958, only 41,459 barrels of oil had been produced from this reservoir. Original oil in place was calculated at 1,564,000 barrels with 203,000 barrels estimated to be recoverable.



WEST DRUMHELLER & DRUMHELLER OILFIELDS
GROSS NISKU OIL PAY ISOPACHS

FIGURE 5

Drilling activity was at its peak in the years 1953 and 1954 with the fields essentially drilled out by the end of 1955. Drilling of the wells was routine, although the terrain near the bank of the Red Deer River presented some difficulties. Lost circulation sometimes occurred with the drilling fluid being lost to Cretaceous coal seams. The average cost to drill and complete a Nisku well in the Drumheller area was $80,000.00. Logging programs generally consisted of an Electrical Log and a Radioactivity Log from total depth to surface.

Conclusion

From the development history of the Drumheller fields it is apparent that continued exploration in a known area may result in additional discoveries. Conditions in this area are favourable for more structural and stratigraphic traps and with further exploration some of them may be discovered. The combined production from the two fields ranked fourteenth amongst Alberta fields in 1958.

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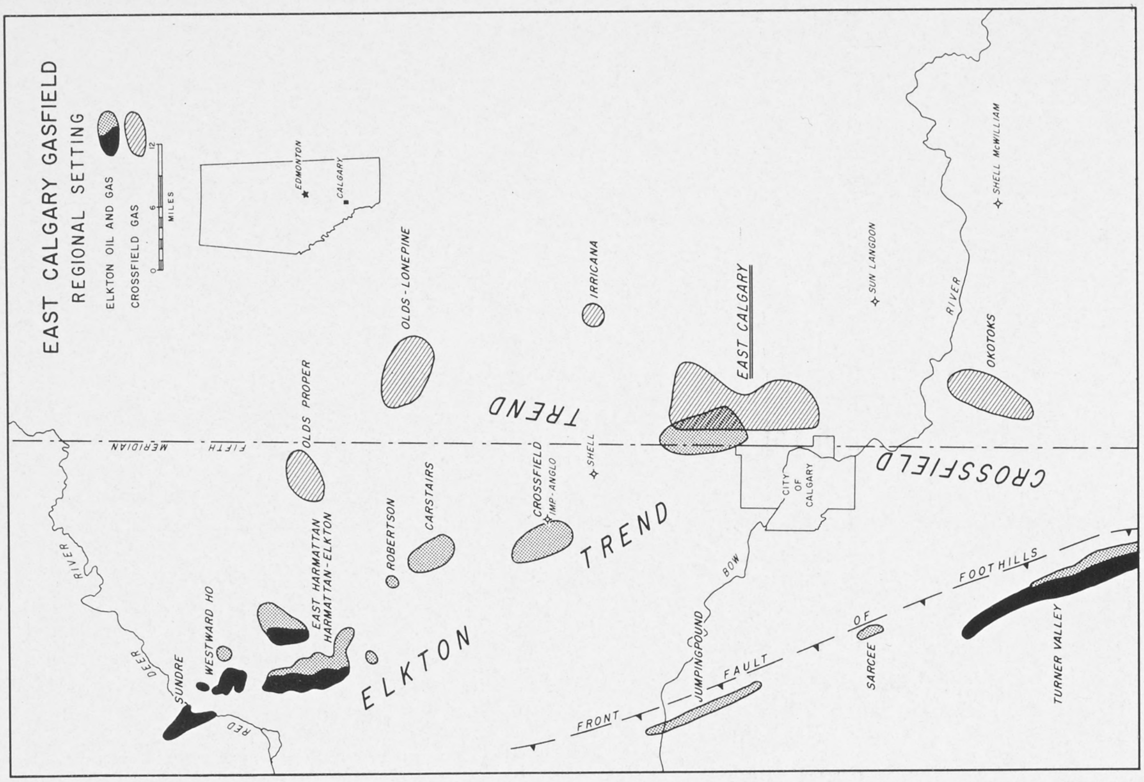

FIGURE 1

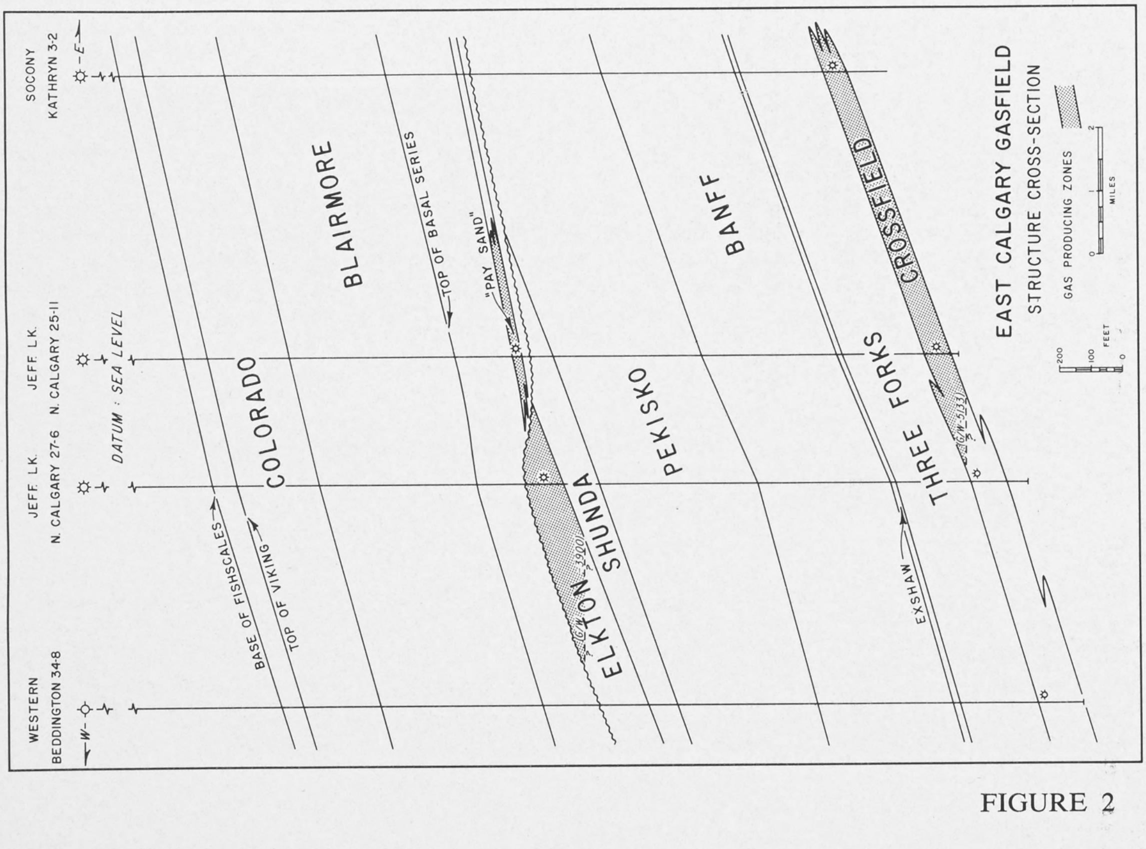

FIGURE 2

EAST CALGARY GAS FIELD [1]

A. D. M. MASON AND C. RIDDELL [2]

ABSTRACT

The East Calgary gas field in southern Alberta is located at the juncture of two trends of stratigraphic traps. The lower reservoir, the Crossfield dolomite member of the Upper Devonian Three Forks formation, contains substantial reserves of highly sulphurous gas trapped by an eastward up-dip porosity pinch-out. The upper reservoir, the Elkton member of the Mississippian Turner Valley formation, contains sizeable wet-gas reserves within a lobe of porous dolomite formed by progressive eastward erosional truncation of the Mississippian surface. Minor gas reserves may be present within Basal Cretaceous sands lying immediately above the Mississippian unconformity. Step-out and infill drilling is continuing slowly within the field area of approximately two townships.

HISTORY OF DEVELOPMENT

Until 1943, deep drilling in the Calgary area had been restricted almost entirely to the search for fields of the Turner Valley type in the Foothills to the west. Turner Valley oil and gas production is obtained from two carbonate members at the top of the Mississippian, the "Upper Porous" and the "Lower Porous". The "Lower Porous" has since been renamed the Elkton member of the Turner Valley formation. In 1943, Shell McWilliam No. 1 (Lsd. 8, Sec. 1, Twp. 21, Rge. 26, W4M.) bottomed at 8,098 feet in the Devonian Jefferson. Only 30 miles southeast of Calgary, this well found neither of the porous Mississippian units. To the north of Calgary, Imperial-Anglo Crossfield No. 1 (Lsd. 9, Sec. 11, Twp. 28, Rge. 2, W5M.) was drilled to 9,526 feet and abandoned in May 1946. Again, the porous Mississippian beds were absent. The bottom of the well was in porous brown dolomite 337 feet below the top of the Devonian Three Forks formation. An attempted test of the porosity was unsuccessful. It is this unit which, though not formally described came to be known by local geologists as the "Crossfield member". It is interesting to note that today this well lies only one mile from Elkton wet-gas production. In 1949, Sun Langdon No. 1 (Lsd. 1, Sec. 3, Twp. 23, Rge. 27, W4M.) was drilled to 8,801 feet in the Jeferson, about midway between Calgary and the McWilliam well, again without finding either of the major producing zones.

A number of highly interesting deep tests were drilled within 50 miles of Calgary during 1951. Three are worth special mention in connection with the subsequent discovery of the East Calgary field. Shell Mackid No. 1 (Lsd. 1, Sec. 19, Twp. 21, Rge. 28, W4M) only 15 miles south of Calgary, established the presence of thick sections of both the Elkton and Crossfield in the area. This well was drilled to 10,501 feet in the Cambrian, and after logging non-commercial gas shows in the Elkton (200 Mcf/d), was completed as the discovery well of the Okotoks field with a potential of 10 MMcf/d of sour gas from the Crossfield. Canadian Superior Robertson 9-26 (Lsd. 9, Sec. 26, Twp. 30, Rge. 3, W5M.), 40 miles north-northwest of Calgary, also completed as a gas discovery in the summer of 1951. It was drilled to 10,556 feet in the Jefferson (Leduc?), finding a thick, wet Crossfield section, and was capped as an Elkton gas well with a potential of 2.06 MMcf/d. Shell Crossfield No. 1 (Lsd. 4, Sec. 22, Twp. 27, Rge. 1, W5M.), just north of Calgary, was abandoned later in the year at 11,289 feet in the Cambrian. Gas at 500 Mcf/d was tested from Blairmore sands; the Elkton was not present, and the Crossfield, though well-developed, yielded only gas-cut mud on test. This well was followed immediately by Shell Olds No. 1 (Lsd. 16, Sec. 11, Twp. 32, Rge. 1, W5M.), 45 miles north of Calgary. Olds No. 1 was drilled to 10,411 feet in the Cambrian, and completed in May, 1952 as the discovery well of the Olds gas field, with a potential of 2.5 MMcf/d of wet gas from the Crossfield. The broad outlines of two producing trends had emerged by this time (Fig. 1). The Crossfield, productive at Olds and Okotoks, and the Elkton, productive at Robertson and present at Okotoks, appeared to meet and cross in the vicinity of the city of Calgary.

The East Calgary field discovery well, Socony-C.P.R. Kathryn 3-2 (Lsd. 2, Sec. 3, Twp. 26, Rge. 28, W4M.) was spudded in January, 1954 by Socony-Vacuum Exploration Co. (now Mobil Oil of Canada Ltd.), as a test of the Cretaceous sands and the Mississippian and Devonian carbonates. Minor gas and oil showings were obtained from sands within the Cretaceous before completing for 1.1 MMcf/d of sour gas from the Crossfield. This well was followed-up in 1955 by Socony Calgary 36-10 (Lsd. 10, Sec. 36, Twp. 24, Rge. 29, W4M.), some 8 miles southwest of Kathryn 3-2. In addition to the prime Crossfield target, the well was located to test the edge

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1 Published by permission of Mobil Oil of Canada, Ltd., and Jefferson Lake Petrochemicals of Canada Ltd.

2 Geologists, Mobil Oil of Canada, Ltd., Calgary, Alberta.

of the porous Elkton dolomite. Unfortuntely, the Elkton present proved to be non-porous limestone. A potential of 23 MMcf/d of very sour gas was obtained from the Crossfield. In 1956, another step-out, Mobil-Canamerican Chestermere 18-11 (Lsd. 11, Sec. 18, Twp. 24, Rge. 28, W4M.) was drilled with similar objectives to that of the Calgary well. Again the Elkton was limestone, but porous and water-laden. A potential of 6.75 MMcf/d was obtained in the Crossfield. These three wells had established Crossfield sour gas production over an arc 10 miles in length and suggested the possibility of Elkton production.

In early 1957, Mobil Oil farmed out its interest in the area to Jefferson Lake Sulphur Co., of Tulsa, Oklahoma (now Jefferson Lake Petrochemicals of Canada Ltd.). Involved in the farmout was about 80,000 acres of C.P.R. leases, Crown P. & N. G. leases, and gas licence lands. Since then, Jefferson Lake has drilled an additional 7 wells to the Crossfield. One of the first, Jefferson Lake-C.P.R. N. Calgary 27-6 (Lsd. 6, Sec. 27, Twp. 25, Rge. 29, W4M.), five miles northwest of the Socony Calgary well, discovered a 117 foot gas-bearing interval of Elkton dolomite. Banff Oils also has an Elkton producer at the north end of the field. All told, 10 wells are capable of production of gas in the area, 6 from the Crossfield only, 3 from the Elkton only, and one from both Crossfield and Elkton, (Jeff. Lake Bull Calgary 11-13-25-29).[3]

Stratigraphy

Some 12,500 feet of sediments ranging in age from Cambrian to Paleocene, with a mantle of Pleistocene glacial deposits at the suface underlie the East Calgary field area. The bulk of this section is well known to Alberta petroleum geologists from first hand association, and has been described, generally or in detail, in numerous published papers. It consists of approximately 1,800 feet of Cambrian, 2,200 feet of Devonian, 1,100 feet of Mississippian, 5,600 feet of Cretaceous and 1,800 feet of Tertiary and Recent beds. The section as deep as the upper part of the Devonian is known from wells in the immediate field area. Wells have reached the Cambrian as near as Okotoks and Crossfield, but the closest Precambrian tests are 50 or 60 miles distant.

The Cambrian in the field area is estimated to be some 1,800 feet thick. Distant borings that have penetrated the full Cambrian section suggest that under the East Calgary field the lithology will in all likelihood be partially carbonates and partially clastics, suggesting an intermediate position between the thick carbonate sequence of the mountains and the sand-shale series of the plains to the east.

About 2,200 feet of Devonian sediments overlie the Cambrian. The basal unit is Middle Devonian Elk Point group, consisting of about 50 feet of limestone and dolomite with red and green shales. The bulk of the Devonian, above the Elk Point, is Upper Devonian and is divided into three parts, the Jefferson limestone, the Jefferson dolomite, and the Three Forks formation.

The Jefferson limestone is the equivalent of the combined Cooking Lake and Beaverhill Lake. The Jefferson dolomite is equivalent to the Nisku, Ireton, Leduc and Duvernay formations of the "Green Shale Basin" areas, but no such breakdown is possible in the East Calgary field area. Crystalline dolomites occupy an 800 foot interval, with only minor sporadic porosity developments. Considerable anhydrite is present, interbedded with the dolomites, intergrown, or filling pore spaces.

The Three Forks formation is correlative with the Big Valley, Stettler, Graminia and Calmar formations of central Alberta. It consists almost entirely of dolomite and anhydrite interbeds. At the top, which is also the top of the Devonian section, is a limestone unit of some 20 feet, equivalent to the Big Valley formation. The main productive zone of the field, the Crossfield member, is a dolomite developed within the Three Forks, some 250 feet below the top.

The Crossfield member in the centre of the field area is roughly 140 feet thick and consists mainly of brown dolomite, cryptocrystalline to fine crystalline with poor to fair, fine-vuggy porosity and minor intercrystalline porosity. Contacts with the underlying and overlying evaporitic sequences are indistinct and considerable interfingering of the Crossfield and the evaporitic rocks occurs. Present control indicates lateral continuity throughout the field and surrounding area, with the Crossfield grading into an evaporitic sequence to the east of the field area. The pool is limited by porosity pinch-out within the Crossfield to the north, east and south and by water down-dip to the west. This porosity pinch-out is distinct from the lithological pinch-out of the Crossfield itself.

3 Editor's Note: This is a recently standardized abbreviation of the well name, by the Oil and Gas Conservation Board.

A Mississippian sequence 1,100 feet thick is present over much of the field. Truncation by erosion thins these beds from west to east until only 860 feet of Mississippian is present at the Kathryn well on the extreme east edge of the field. Where the full 1,100-feet section is preserved, it is made up in ascending order of about 450 feet of Banff-Exshaw, 450 feet of Pekisko formation, 100 feet of Shunda formation, and 100 feet of Elkton member of the Turner Valley formation. The Banff formation is predominantly argillaceous limestone of a dark grey-brown color. Beds of buff fragmental limestone, and grey-black shale are common. Shale content increases towards the base, with the thin bituminous black shale of the Exshaw formation lying abruptly on the Devonian Three Forks formation. The Pekisko is made up of buff fragmental limestones for the most part, apparently calcarenitic bank deposits. There is a sizable argillaceous content, and towards the base some siliceous material. The Shunda formation averages slightly over 100 feet thick where totally preserved, and consists of grey-brown argillaceous limestones with considerable silt content. The Turner Valley formation is represented by its basal member, the Elkton, which is the second major productive zone of the field.

The Elkton member is typically white to grey-buff dolomite, very fine to medium crystalline, fossiliferous, with fair vuggy and minor intercrystalline porosity. Atypical sections occur in Jeff. Lake Bull Calgary 11-13-25-29 and Socony Calgary 36-10. The former well has a tight section of white to grey-buff calcareous dolomite, very fine crystalline, with minor vuggy porosity, overlying typical Elkton; in the latter well the Elkton consists of white to grey-buff limestone, very fine to medium crystalline, chalky in part, slightly fossiliferous with very minor vuggy porosity. It is thought that this tight limestone facies to the south of the Elkton production may be a porosity barrier limiting the pool, although the main controlling factor is erosional truncation of the Elkton.

Some 5,600 feet of Cretaceous is present, made up of five major units, the Blairmore formation, the Colorado group, the Lea Park, Belly River, and Edmonton formations. The Blairmore varies from 650 to 800 feet in thickness, with most of this variation caused by infill on the irregular Mississippian erosional surface. The lower part of the Blairmore is predominantly sandy, but, although oil staining is prevalent, very little porosity is developed. The only production indicated to date is in the Jefferson Lake-C.P.R. N. Calgary 25-11 well, where a Basal Blairmore sand with 8 feet of porosity gave up on drillstem testing, 6.2 MMcf/day of wet gas (12 bbls. of condensate per MMcf). The structure cross-section (Fig. 2) shows the position of this sand relative to the Elkton erosional edge, and indicates the possibility of an interconnected reservoir; this is substantiated by the similarity of gas analyses for the two zones. Above the near-shore sands of the lower Blairmore, are brackish and continental beds of sand, shale, and silt, with much carbonaceous material and some coal beds. The Blairmore-Colorado contact is not well marked. Generally Blairmore sandstones have a greater calcareous content and no glauconite, while the Viking sands near the base of the Colorado are less limy and contain minor amounts of glauconite. The Viking sands show scattered oil staining but little porosity. The remainder of the Colorado and the Lea Park is a shale section similar to that found across the Plains. The feather edge of the Cardium sand reaches the west side of the field. Western Beddington 8-34 (Lsd. 8, Sec. 34, Twp. 25, Rge. 1, W5M.) was completed as a sub-commercial Cardium oil well in 1957, but no other shows have been encountered nearby. Above the Lea Park, the Belly River and Edmonton formations form a monotonous succession of almost 2,600 feet of sandstones, sandy shales, siltstones, carbonaceous shales, coal, and shale. The Paleocene Paskapoo formation continues this non-marine section another 1,800 feet to the surface, which is covered by some 50 feet of glacial till and alluvium.

STRUCTURE

The East Calgary gasfield is situated on the east limb of the Alberta syncline. Dip is almost due west, at 50 feet to the mile in the Cretaceous, and at 75 feet to the mile in the 'Palaeozoics'. Immediately to the east of the field, these dips lessen, indicating a hinge-line. This feature is best illustrated by the contours on the Crossfield (Fig. 3) where a noticeable increase in spacing occurs east of the field area.

Structure on the Crossfield is homoclinal, only minor undulations disturbing the surface. The up-dip (eastward) disappearance of Crossfield porosity roughly coincides with the position of the structural hinge-line of the edge of the Alberta syncline. However, as the Alberta syncline was not present in Devonian times, it is suggested that this positioning is merely coincidental. The porosity pinch-out is related to primary depositional conditions, although subsequent fluid circulation has undoubtedly modified it.

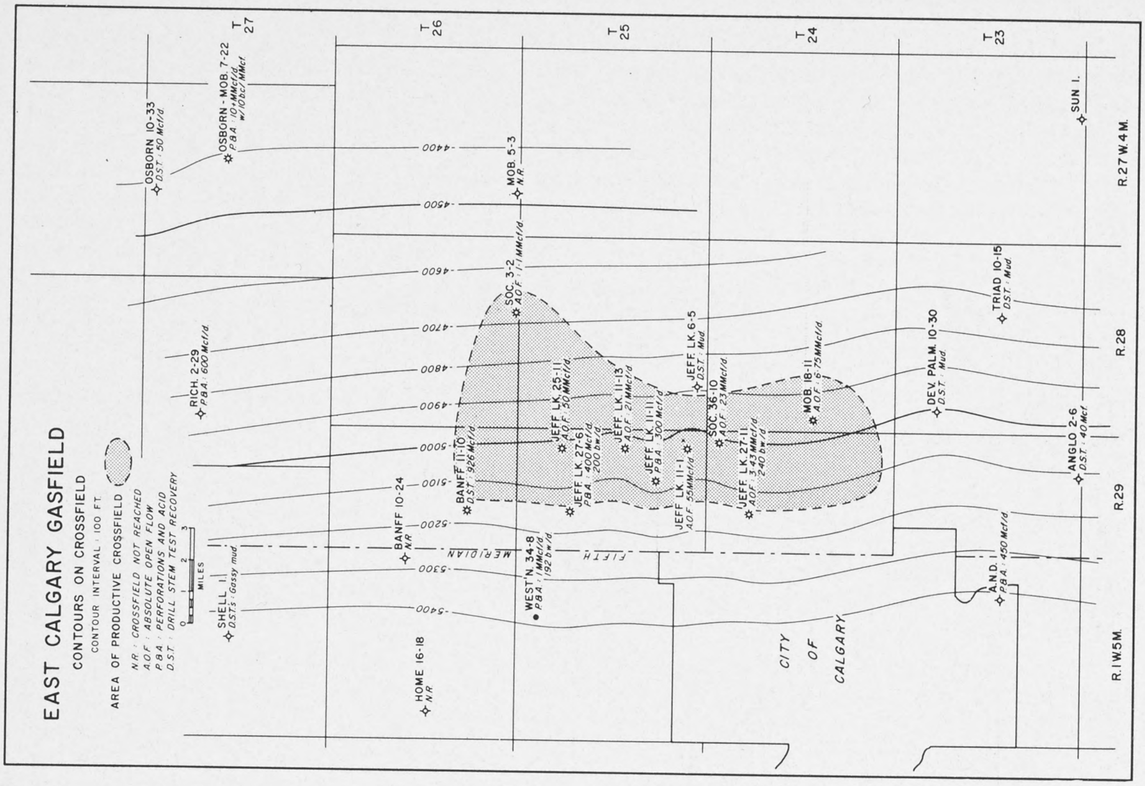

FIGURE 3

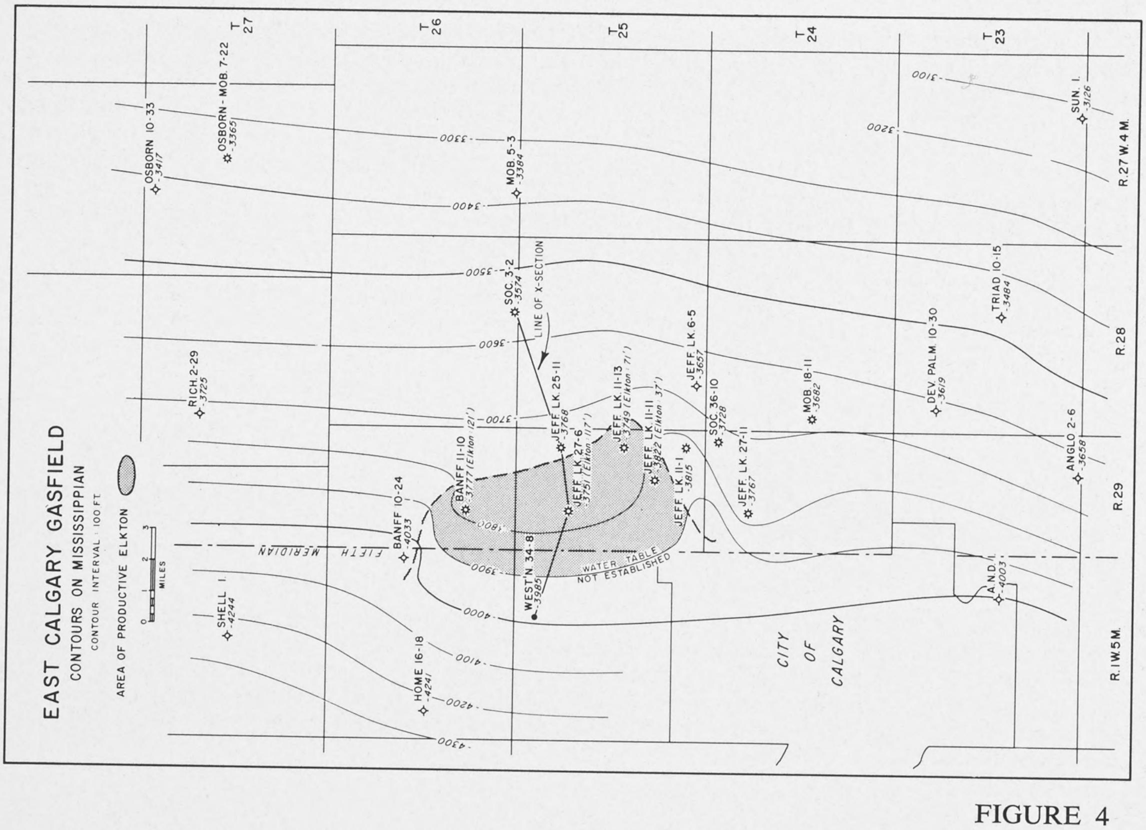

FIGURE 4

Structure within the Mississippian is similar to the Crossfield. The base of the Elkton is a westward-dipping homocline. The upper surface of the Elkton (Fig. 4) is markedly affected by erosion, and the removal of this unit towards the east forms the regional up-dip closure on the entire trend. Channelling into these dolomites appears to form the local traps along the length of the trend, and the East Calgary Elkton pool is a good example of this type of feature. In addition to these eroded channels there is a possibility that a tight limy facies of the Elkton may form a porosity barrier at the south end of the productive lobe. Details of this facies are found in the discussion of Elkton statigraphy.

The rather pronounced topographic feature formed by the eroded edge of the Elkton could be expected to exert some effect on the overlying Cretaceous sediments, but the infilling of topographic irregularities by the Basal Blairmore beds tends to level off this feature. The lowest readily mappable horizon in the Blairmore shows only terracing over the Elkton edge, and no closure can be mapped on any Cretaceous horizon.

Except for the effect of regional west dip, structure plays no part in the East Calgary accumulations.

Reserves

With development drilling still in the early stages, reservoir parameters are not firmly established. Porosity and permeability factors are quite variable, with permeability in particular being critical in a well's performance. Acid is used to stimulate all wells, and in the Crossfield especially has a marked effect in increasing the productive capabilities. Microfracturing, which is common in the Crossfield, appears to be very susceptible to acidizing.

The Elkton gas is wet, averaging 20 barrels of condensate per million cubic feet of gas, and has a variable hydrogen sulphide content of about 1 percent. Crossfield gas has little or no condensate, and is highly sulphurous. The hydrogen sulphide in the Crossfield appears to be subject to gravity segregation within the reservoir. The content at Kathryn 3-2 in the highest part of the field, is 12.5 percent hydrogen sulphide, while in the lowest part at the water line it approaches 39 percent hydrogen sulphide. In the present area of development, an average content in excess of 30 percent is indicated, which will yield over 10 long tons of sulphur per million cubic feet of raw gas produced.

In the present state of development, only preliminary figures can be presented, those below being the most recent.

Reservoir Characteristics *

	Elkton	Crossfield
Average well depth (feet)	7,400	8,500
Productive area (acres)	22,200	35,400
Average pay (feet)	51.6	56.1
Average porosity (percent)	7.41	4.36
Average connate water (percent)	25	25
Reservoir pressure (pounds/sq. inch)	3,020	3,640
Disposable gas (billions of cubic feet)	448	334

* From City of Calgary submission to Alberta Oil and Gas Conservation Board, January, 1959.

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WAYNE OIL FIELD, ALBERTA

R. H. ERICKSON AND J. S. CREWSON[2]

Abstract

The Wayne Oil Field is located in south-central Alberta, and since its discovery in 1954, has produced over 320,000 barrels of 29.5° A.P.I. oil from the Lower Cretaceous Sunburst sandstone. The sandstone is characterized by a clay infilling which reduces production but causes the trap. Of seven wells drilled, six are on pump and one is suspended.

Location

The Wayne Oil Field is in south-central Alberta, 60 miles east-northeast of Calgary, and 10 miles south of Drumheller (Fig. 1). The pay unit is located stratigraphically in the Sunburst sandstone member of the Lower Mannville formation of the Lower Cretaceous.

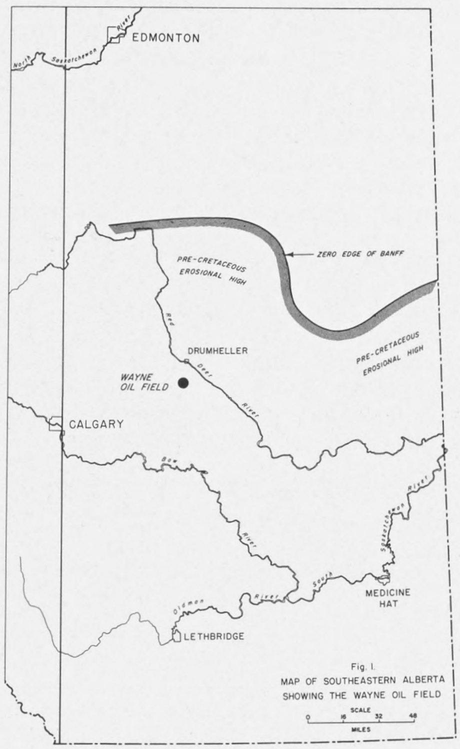

Fig. I.
MAP OF SOUTHEASTERN ALBERTA
SHOWING THE WAYNE OIL FIELD

FIGURE 1

History of Discovery

In the Wayne area, the tempo of exploration activity increased following the discovery of Devonian oil at Drumheller in 1951. Great Plains Development Company of Canada, Ltd., and its partner, Triad Oil Co. Ltd., acquired a farmout in 1952 from Socony Vacuum Exploration Co., (now Mobil Oil of Canada Ltd.), whereby an acreage interest could be earned by drilling a well into the Beaverhill Lake group. After a geophysical evaluation, the earning well was drilled in Lsd. 15, Sec. 13, Twp. 27, Rge. 20, W4M. The Devonion objective was unproductive, and the well was plugged back and cased as a suspended Sunburst sandstone gas well in October, 1952. The possible existence of an oil column downdip was suggested by oil recoveries of 5 and 10 feet respectively, on successive tests below the tested gas interval in the basal part of the Sunburst. Great Plains and Triad entered into another agreement with Mobil Oil, whereby further acreage could be earned by additional drilling. Three wells were then drilled downdip at a distance thought to be below the gas/oil contact. The Sunburst was undeveloped or tight in the first two wells, although the second was cased as a Viking gas well.

2 Geologists, Great Plains Development Company of Canada, Ltd.

The third well, Great Plains-Triad-Socony-C.P.R. Wayne A6-22 in Lsd. 6, Sec. 22, Twp. 27, Rge. 20, W4M. discovered 29.5° A.P.I. oil in the Sunburst. The well was completed September 3rd, 1954 with an initial potential, determined after a five day production test, of 262 barrels of oil per day through a ¼ inch choke. The average gas/oil ratio was 531 cubic feet per barrel.

STRATIGRAPHY

A review of the Lower Cretaceous strata, which contains the pay zone, is given below. Glaister's (1959) correlation and names are used throughout. For further stratigraphic information the reader is referred to Allan and Sanderson (1945),-Pleistocene through Upper Cretaceous; Glaister (1959),-Lower Cretaceous; Penner (1959),-Mississippian; Andrichuk and Wonfor (1954),-Devonian; and Belyea (1957),-Devonian.

The top of the Lower Cretaceous is represented approximately by the base of the Fish Scale sandstone. The uppermost Lower Cretaceous rocks consist of about 115 feet of dark grey marine Colorado shales with minor siltstone and sandstone lenses.

The Viking formation underlies Colorado shales and has an average thickness of 190 feet in the Wayne field. Some sand development occurs in the top 60 feet, with porosity being confined to a chert-pebble conglomerate. The chert pebbles are predominantly black, well rounded, and up to two inches in diameter. Several wells in the area flowed gas from the top of the Viking. The Joli Fou formation, which underlies the Viking, is represented by 100 feet of dark grey marine shales with minor lenses of siltstone and standstone.

The Joli Fou is underlain by the Mannville group. The Upper Mannville formation consists of approximately 345 feet of grey, non-marine, calcareous, sideritic shales, argillaceous sandstones, siltstones, and several well developed coal beds. The bottom 60 feet is correlatable with the Glauconitic sandstone (Workman, 1958) and is composed of light grey, fine grained, quartzose sandstone with poor porosity and oil staining. No appreciable amounts of glauconite are present.

The uppermost member of the Lower Mannville is the "Calcareous" member or, as commonly known in central Alberta, the "Ostracod" zone (Fig. 2). In the Wayne field it is represented by approximately 35 feet of medium grey shales with interbeds of buff to grey, cryptocrystalline limestone and a very thin carbonaceous band. Ostracods are rare, but thin-shelled pelecypods and plant remains are common.

CROSS SECTION OF THE LOWER MANNVILLE FORMATION IN THE WAYNE FIELD

(LINE OF SECTION SHOWN IN FIGURE 3.)

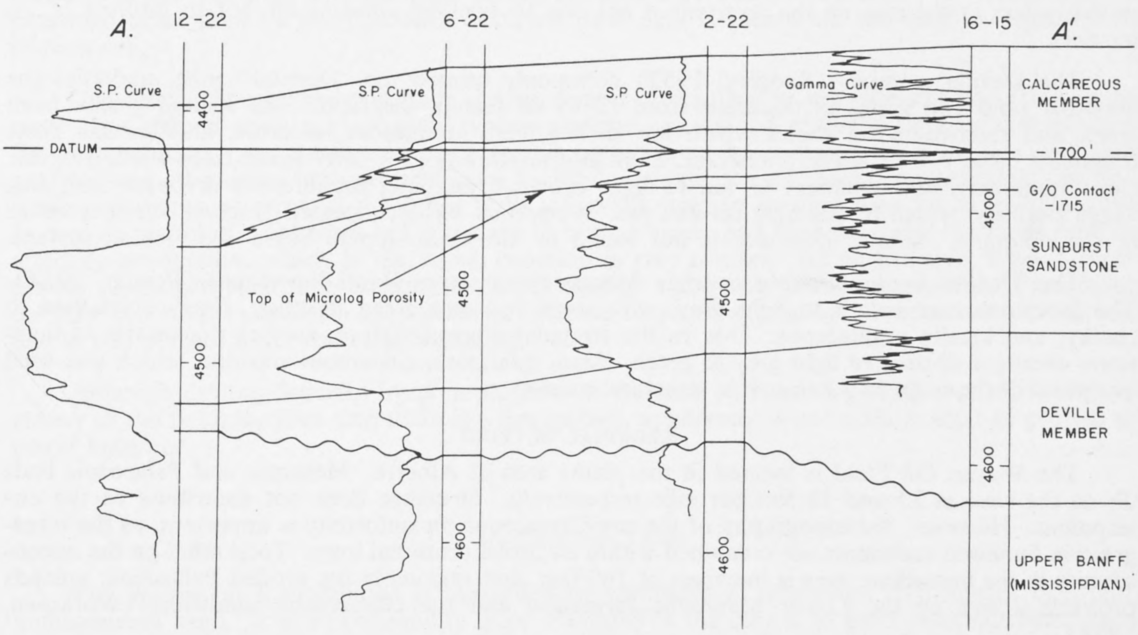

FIGURE 2

The Sunburst sandstone member underlies the "Calcareous" member. In the Wayne area the sandstone is light grey to brown, medium grained (average median diameter 0.286 mm.), quartzose, angular to sub-angular, very well sorted (average sorting coefficient 1.38), and friable. The sand becomes coarser and has more fragments of other rocks toward the base. Some very small gravity faults are observable in the core. The average gross thickness is 65 feet.

The abundance of interstitial clay and very thin shale partings detract from the economic potential suggested by the above description. Generally, where the rock is light grey and not oil stained, there is an increased clay content and no effective porosity. In 13 sieved samples the less-than-sand size fraction varied from 3.7 to 13.5 percent by weight. The interstitial clay is white and occurs in the cleanest sandstone as a dusting or coating on grains, but may increase to partial and even complete infilling between grains. Infilling increases toward the base.

Six samples containing the clay fraction were sent to the Research Council of Alberta for analysis. Particular stress was placed on determining the presence or absence of expanding-type clays. P. J. S. Byrne conducted the study and the following information is drawn from his report. By means of X-ray diffraction he studied the fraction of each sample which measured less than two microns. The results of the investigations are summarized in Table 1.

TABLE 1

MINERALOGY OF CLAY-SIZE FRACTION FROM SUNBURST SAND SAMPLES

LOCATION	DEPTH	KAOLINITE	ILLITE	MIXED LAYER MINERAL	QUARTZ	CALCITE
6-22-27-20-W4M.	4,477	Maj.	Tr.	Tr.	Maj.	—
6-22-27-20-W4M.	4,501	Dom.	Min.	Min.	Mod.	—
6-22-27-20-W4M.	4,521	Dom.	Tr.	Tr.	Mod.	—
4-22-27-20-W4M.	4,475	Dom.	Min.	Tr.	Mod.	—
4-22-27-20-W4M.	4,507	Dom.	Tr.	Tr.	Mod.	—
4-22-27-20-W4M.	4,561	Maj.	Tr.	Tr.	Maj.	Tr.

Legend: Dom: dominant Maj: major Mod: moderate Min: minor Tr: trace

The relatively uniform results obtained from all samples show that the non-clay constituents are quartz with a trace of calcite and the clay constituents are kaolinite, illite and to a minor extent a mixed-layer mineral. This latter mineral is compatible with the chlorite-illite assemblage but might belong to a rarer clay. In any case, results indicate that the illite contains a minimum of swelling clay and the less important mixed-layer mineral does not contain a large proportion. The serious effect of the clay on the reservoir is not due to swelling constituents but to infilling of interstices.

The Deville member (Badgley, 1952) commonly termed the "Detrital" zone, underlies the Sunburst sand and varies in thickness from 12 to 68 feet in the field. The section grades from green and reddish-brown shales which are slickensided, arenaceous, sideritic, and contain chert fragments up to two inches in diamenter, to an intermixture of grey, silty shale, large white irregular chert fragments, and boulders of tan to light brown crystalline, fossiliferous dolomite with fine vuggy porosity, which bleeds light oil and gas. Numerous bitumen coated fracture surfaces occur in the dolomite. Similar dolomite is not found in the Mississippian below the erosion surface.

The Deville unconformably overlies Mississippian upper Banff limestones (Penner, 1958). The limestones are cream to light grey, with some red and green mottling, finely crystalline to chalky, and locally argillaceous. Due to the irregular erosion surface, varying thicknesses of limestone overlie a distinctive light grey to green, clean, quartzose, calcareous siltstone, which was used in several of the wells as a Palaeozoic structural marker.

REGIONAL SETTING

The Wayne Oil Field is located in the plains area of Alberta. Mesozoic and Palaeozoic beds dip to the west at 25 and 35 feet per mile respectively. Structure does not contribute to the entrapment. However, the topography of the pre-Cretaceous unconformity is important, as the transgressive Sunburst sediments are contained within its broad erosional lows. Total relief on the unconformity in the immediate area is in excess of 100 feet, but regionally the eroded Palaeozoic uplands protrude above all the Lower Mannville formation and the Glauconitic sandstone (Workman, 1958).

Wayne is about 160 miles from the type locality of either the Sunburst or the Ellerslie sands — a considerable distance to carry such a unit. If an established name is desirable, the term Sunburst seems more appropriate than Ellerslie as the white clay infilling is an important characteristic of the former. The sandstone is, however, particularly quartzose and well sorted except toward the base, suggesting the possibility that it is partially composed of Ellerslie-type sand. Glaister (1959) states that an eastern source appears to have been a significant contributor to the Ellerslie sand in east-central Alberta, whereas in southwestern Alberta a western source for the Sunburst sandstone is indicated. Toward the base an increase in auxiliary minerals and clay seem to clearly justify the Sunburst appellation and importance of a western source.

Kaolinite, as found in the clay constituent of the pay sand, is indicative of a source which was subjected to prolonged weathering. It seems feasible that the direct source of the clay was from the underlying Deville member. Previously the underlying argillaceous Banff formation may have provided abundant residual clay to the Deville in this area. Beyond the erosional edge of the Banff, Ellerslie ortho-quartzites were deposited on a relatively clean Devonian carbonate surface and appear to be much less contaminated by argillaceous infilling. Cross-sections by Badgley (1952) tend to support this relationship by showing little or no Deville in many wells where there is a thick Ellerslie.

Reservoir and Production Characteristics

The gross pay intervals, determined from log and core analyses, vary from 32 to 93 feet with an average of about 65 feet in the seven wells drilled. The net microlog porosity average is 60 feet. Where the permeability exceeds 10 millidarcys, the average sand thickness is 31.8 feet, with an average porosity of 17 percent and an average horizontal permeability of 70 millidarcys. Individual values for each well are shown in Figure 3. The dominant producing mechanism is solution gas. An oil/water interface has not been established, but a gas/oil interface is indicated in No. 16-15 well at 1,715 feet subsea.

To the end of 1958, cumulative production amounted to 318,409 barrels. This figure is not as large, nor is production as equitable among the wells as the log and core analyses data indicate it should be. Microlog porosity isopachs or maps involving core analyses data are not parallel to a rather disappointing production history shown by iso-production lines in Figure 3. The reason for the discrepancy is the interstitial clay, clay bandings, and very small gravity faults in the sand which in varying degrees serve to give false porosity and disrupt permeability. Because conventional methods of net pay zone determination do not reflect the productive capability, no "contouring" is presented other than barrels produced. Conventional data is placed on the map in Figure 3 for comparison.

One factor thought to be a guide, is the degree of staining or non-staining occurring in the core. The stained areas are generally porous and the non-stained generally tight or shut off from the accumulation. An attempt to evaluate this observation by a comparison of logs and core analyses and oil staining is shown in Figure 4. While the comparison shown concerns only one well, similar relationships exist in the other wells. The oil staining method may be as good a guide as core or microlog evaluations but is subject to human error, and does not solve the basic problem affecting production, which is the rapid variation in clay content. As an example, Plate 1 shows porous oil-stained sandstone abutting vertically against tight, clay-infilled sandstone. Presumably the clay content also causes a proportionate increase in water saturation. Production has included one to two percent water from the beginning.

Although drilling downdip from an oil show at the base of a tested gas interval led to the discovery of the field, the idea that there is a connection, apparently is not valid in light of present reservoir behavior.

Nature of Trap

The Wayne oil accumulation is controlled by variations of interstitial clay content in a fairly homogeneous sand. It is a permeability trap. Harmful as the clay is to good reservoir behavior, it is also the probable reason for the accumulation.

WAYNE OIL FIELD

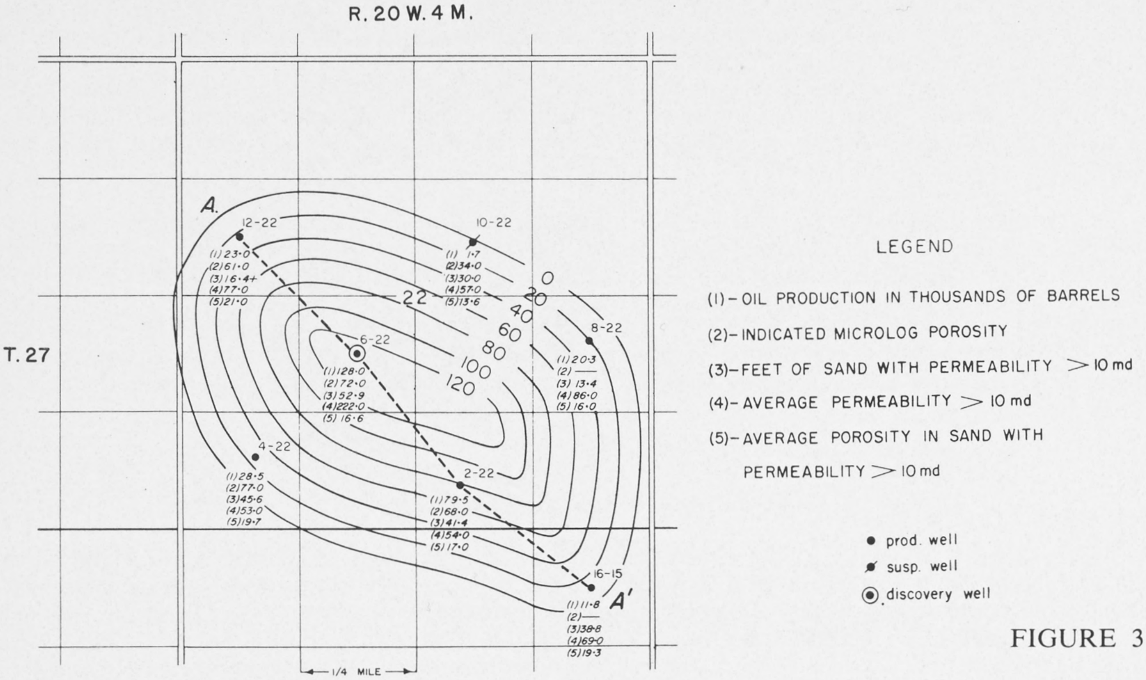

FIGURE 3

ISO-PRODUCTION MAP SHOWING CUMULATIVE PRODUCTION IN THOUSANDS OF BARRELS FOR FIRST 42 MONTHS PER WELL

GREAT PLAINS-TRIAD-SOCONY-C.P.R. WAYNE A6-22

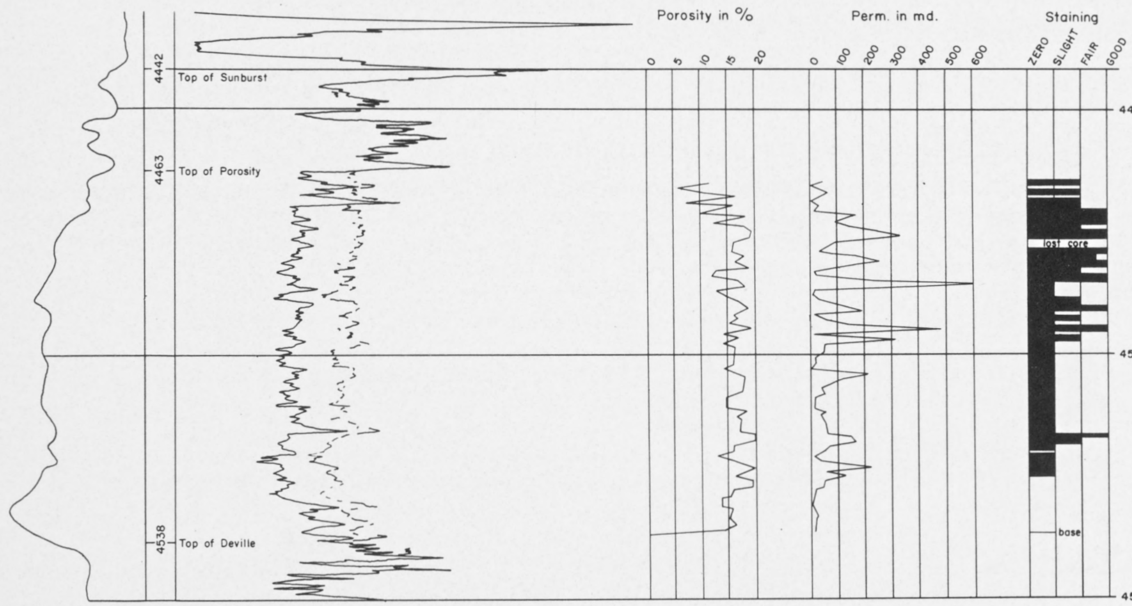

FIGURE 4

COMPARISON OF MICROLOG, CORE ANALYSES AND OIL STAINING IN CORE

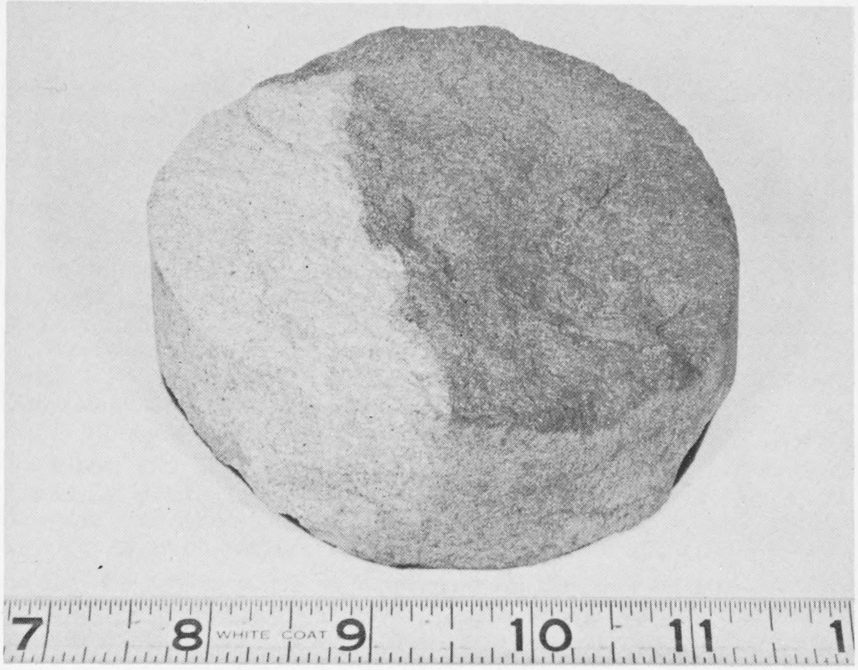

PLATE I

Drilling and Completion Practice

Six wells were drilled on even-numbered legal subdivisions of Section 22 and one on Lsd. 16, of Section 15. Of the seven wells originally drilled, six are still producing on pump and one, No. 10-22, is suspended. The complete porous section of the Sunburst sandstone was cored in all wells except the upper 26 feet in No. 12-22.

During early development drilling, continuous dipmeter surveys were run in an effort to learn more of the location of the field with respect to the geometry of the underlying erosional valley. It was felt that sedimentation and porosity may have been influenced by the unconformity. The validity of the idea was not confirmed as results were inconclusive.

All the wells were cased-through on completion and were both bullet and jet perforated over large portions of their pay intervals. With the exception of No. 6-22 all of the wells were fractured upon completion, without particularly encouraging results. Two wells, No. 2-22 and No. 8-22, received an acid wash and squeeze.

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FIELD TRIP ROAD LOGS

H. W. WOODWARD, AND COMMITTEE [1]

INTRODUCTION

The following road logs and illustrations have been prepared as guide material for field trips to the Drumheller Area and Moose Mountain Area (See Fig. 1).

In order that delegates on the field trips benefit most, transportation will be by chartered bus, and a geologist-guide equipped with public-address system will acompany each bus to comment on geologic features along the route. Selected geologists well informed about specific geologic features will give prepared commentary at field-trip stops.

The first trip, to the Drumheller Area, is planned for Friday, September 11. The locale of this trip offers us an opportunity to observe a fine Upper Cretaceous continental and marine sequence and to obtain an introduction to the fascinations of vertebrate paleontology. The geomorphology of the Badlands along the Red Deer River Valley is striking; Pleistocene geology is grandly exhibited. All of these geologic features, as well as aspects of the coal, oil and gas industries of the Drumheller Area, will be discussed on our trip.

Our second trip, on Saturday, September 12, crosses the Foothills belt and Front Ranges at the latitude of Elbow and Little Elbow Rivers. This traverse of the Disturbed belt offers many excellent exposures of diverse, complex structures, and possibilities for close-hand examination of Lower Mesozoic and Palaeozoic stratigraphy. This trip is short and consequently affords much time for close study of outcrops.

The road log, Calgary to Banff, is supplied to fill the need for geologic commentary of a route travelled often by most of us, and we hope, also, by our visiting delegates on the Sunday following our Conference.

The geology magnificently exposed along these several routes cannot be fully appreciated in a single visit. It is hoped that all our delegates will travel these routes many times and that the logs and accompanying illustrations will be of service to them.

ACKNOWLEDGMENTS

The composition of the road logs has had a long history; most were prepared in preliminary form as early as 1956 by the Society's Road Logs Committee. Preliminary logs for the Drumheller trip were prepared by Messrs. P. Chamney, A. Broscoe and H. W. Woodward. Final draft and field checks were made by the latter two. Preliminary logs for the Foothills and Front Ranges trip were prepared by R. Tennant and H. W. Woodward; final draft and field checks were made by the latter and D. Bossart. Figures accompanying these logs were drafted by The British American Oil Company, Shell Oil Company and Imperial Oil Limited. Sources of photographs are acknowledged separately with the accompanying figures.

Most of the material recorded in these logs is compiled from maps of the Field Trip areas published by the Geological Survey of Canada and by the Research Council of Alberta. (See selected references in list below). Some material has been obtained from newspapers, periodicals, and many other miscellaneous publications. Through our editor, Mr. G. H. Austin, it was possible to co-ordinate the needs of the Road Logs Committee for areal maps and other figures with the requirements of authors of technical papers in this book. By cross-references it has been possible to make joint use of illustrations which appear elsewhere in the book. Thus the technical papers and the road logs are integrated and cost of reproduction and publication has been reduced considerably.

The chairman of the Road Logs Committee and the Society are indebted to these many individuals and companies.

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1 The British American Oil Company Limited, Calgary, Alberta; for Committee members, see Acknowledgments.

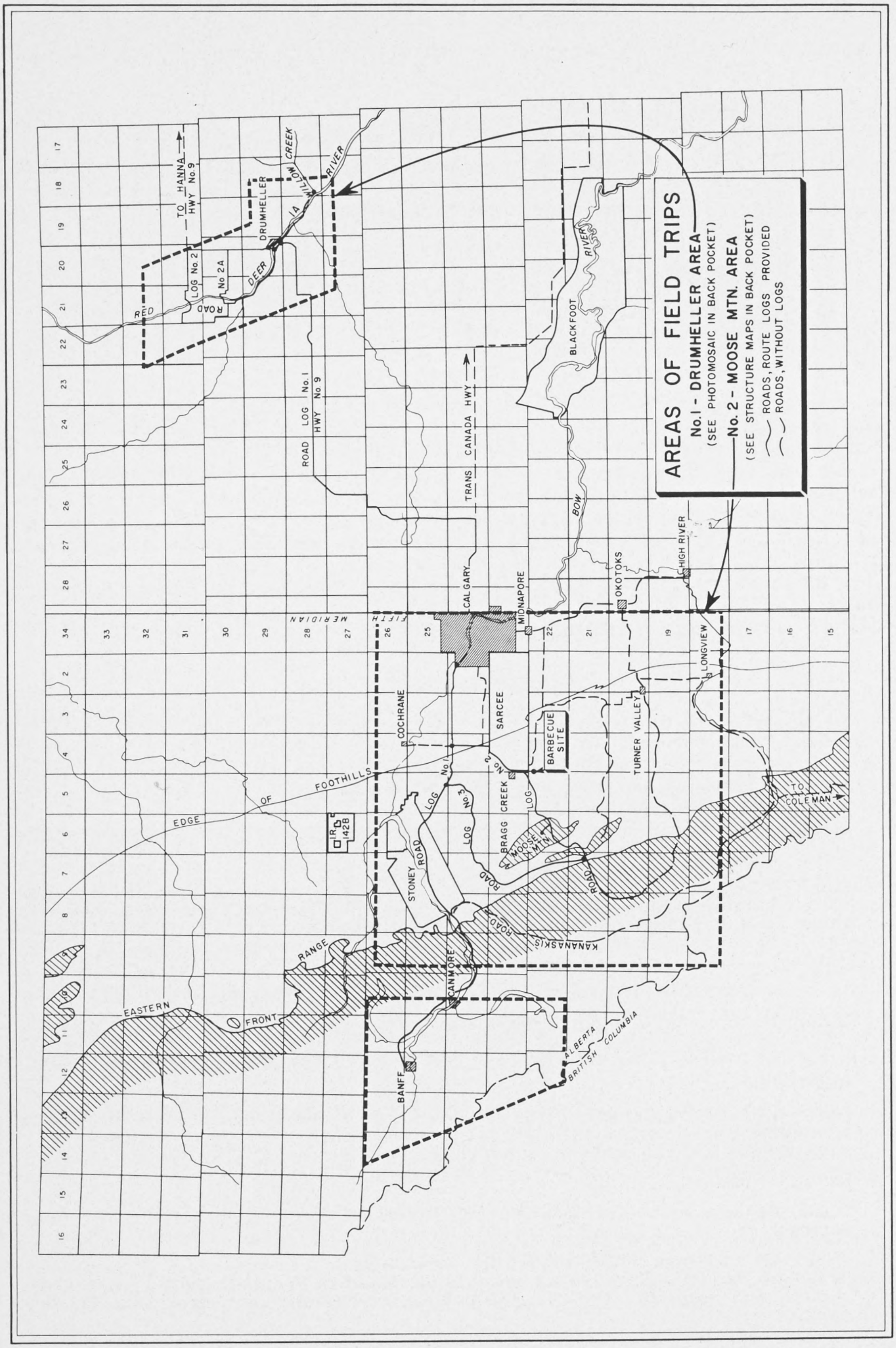
AREAS OF FIELD TRIPS
No.1 - DRUMHELLER AREA
(SEE PHOTOMOSAIC IN BACK POCKET)
No. 2 - MOOSE MTN. AREA
(SEE STRUCTURE MAPS IN BACK POCKET)
ROADS, ROUTE LOGS PROVIDED
ROADS, WITHOUT LOGS
TO HANNA
HWY No. 9
DRUMHELLER
ROSEDALE
WILLOW CREEK
RED DEER RIVER
ROAD LOG No. 2
No. 2A
ROAD LOG No. 1
HWY No. 9
TRANS CANADA HWY
BLACKFOOT
BOW RIVER
HIGH RIVER
OKOTOKS
CALGARY
MIDNAPORE
FIFTH MERIDIAN
COCHRANE
SARCEE
BARBECUE SITE
TURNER VALLEY
LONGVIEW
TO COLEMAN
EDGE OF FOOTHILLS
IR 142B
STONEY
ROAD LOG No. 1
ROAD LOG No. 2
ROAD LOG No. 3
BRAGG CREEK
MOOSE MTN
KANANASKIS ROAD
CANMORE
EASTERN FRONT RANGE
BANFF
ALBERTA
BRITISH COLUMBIA

FIGURE 1

MOOSE MOUNTAIN AREA

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(1931): Turner Valley, Map 257A; Ibid.

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FIELD TRIP NO. 1 — DRUMHELLER AREA
(See Fig. 1, and Photomosaic in back-pocket)

ROAD LOG NO. 1: CALGARY TO DRUMHELLER BADLANDS

The route leads from the cloverleaf and overpass at the intersection of Trans-Canada Highway (Provincial Highway No. 1) and Provincial Highway No. 2 in northeast Calgary, via Provincial Highway No. 9, to Drumheller. Accordingly, the route traverses the inner part of the east limb of the Alberta syncline and crosses, eastward, successively older beds of the Paskapoo and Edmonton formations. Except in the Drumheller district, outcrops of these rocks are rare. On the west third of the route the bedrock is covered by Pleistocene ground moraine, and consequently the topography is gently rolling. On the eastern two-thirds of the route, glacial lake, deltaic, river and flood-plain sediments control topographic features.

Mile:	
0.0	Highways intersection 16th Avenue northeast, Calgary; overpass and cloverleaf at junction of north-south Highway No. 2, and east-west Highway No. 1; continues east on No. 1. Provincial Highway No. 1 is Alberta segment of Trans-Canada Highway leading westward from Medicine Hat near Saskatchewan border, about 350 miles to Continental Divide near Field, British Columbia.
0.0 to 30.0	Route underlain by Laurentide glacial ground moraine. Note typical rolling topography and generally poor drainage. Elevations decrease eastward from 3,500 to 3,200 feet.
4.2	Railway crossing.
5.9	South — Rural road leads to well-sites of East Calgary gas field. Gas and distillate are produced from Mississippian Elkton member and sulphur-rich gas is produced from Upper Devonian Crossfield member. Open flow rates range from 8,000 to 64,000 Mcf per day. Discovery well, Socony Calgary 10-36 (Lsd. 10, Sec. 36, Twp. 24, Rge. 29, W4M.), completed May 4, 1955. (See paper by Mason and Riddell in this book).
8.2	Irrigation ditch from Chestermere (reservoir) Lake.
9.2	Junction. Continue west on Highway No. 1
	Southwest — Highway No. 1A leads 5 miles through Forest Lawn to southeast Calgary.
13.4	Railway crossing.
15.4	Junction (Langdon Corner). Turn north on Highway No. 9, which leads 70 miles to Drumheller and about 200 miles to Alsask on Saskatchewan border. Highway No. 1 leads east to Medicine Hat and Saskatchewan border.
17.6	Railway crossing.
20.6	Masts, Department of Transport Aircraft Directional Radio Beam, in line with east approach to Calgary airport, McCall Field.
27.4	Crossroads. Kathyrn is about one mile west; Keoma, one mile east: former is on Canadian National Railway, the latter is on Canadian Pacific Railway. Most of the villages and towns directly off route provide services and supplies to local farming communities.
30.0 to 83.0	Route is underlain by Laurentide glacial ground moraine but with many small areas of glacial lake, river and flood-plain deposits.

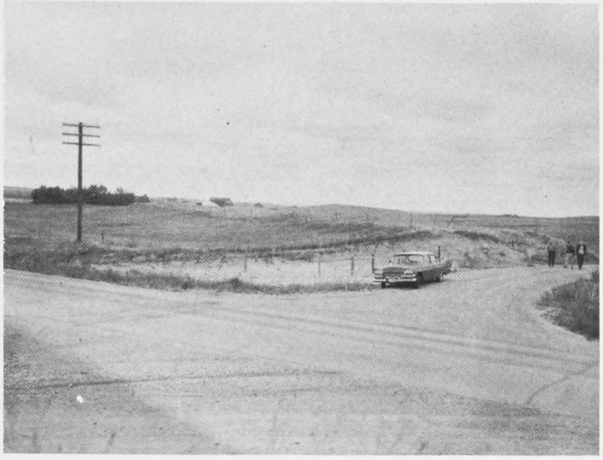


FIGURE 2 — Esker at mile 49.5 Road Log No. 1. Fluvio-glacial sands and gravels with igneous and metamorphic pebbles characterize this sub-glacial deposit. Photograph by A. J. Broscoe.

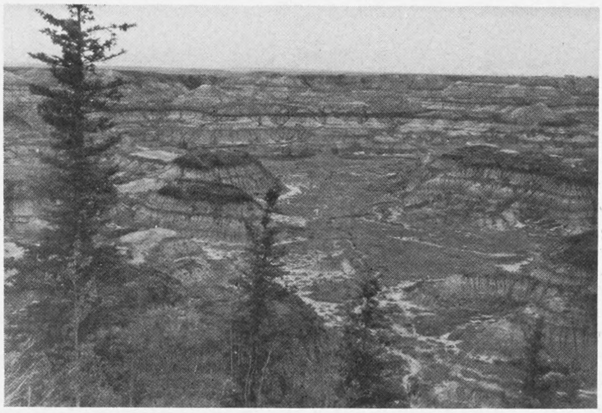


FIGURE 3 — Badlands at Horseshoe Canyon, mile 72.8, Road Log No. 1. Photograph by D. Knight.

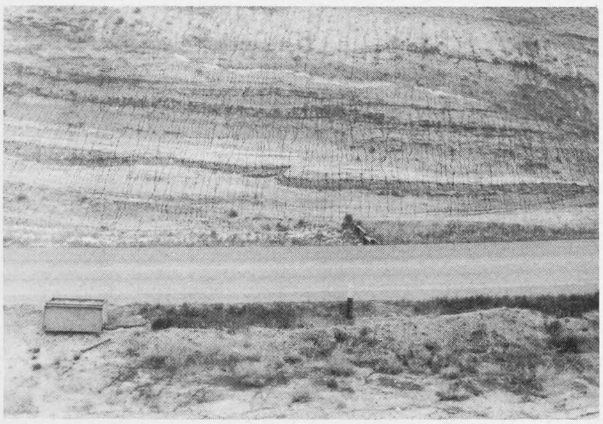


FIGURE 4 — Small reverse fault in Middle Edmonton strata, mile 81.6, Road Log No. 1. Photograph by D. Knight.

30.1 Railway crossing.

37.7 Crossroads. Irricana is about one mile west. Name of village is compound of 'irrigation' and 'canal.' Village is approximate site of 'Slaughter Camp' where members of Palliser Expedition killed 17 buffalo in August 1859.

37.8 Railway crossing.

38.6 West — Pleistocene delta forms terrace in field directly off road.

39.9 Roadside exposures of glacial till.

40.1 Bridge crossing Rosebud Creek.

42.8 Junction. Gravel road west, leads about one mile to Beiseker, named after Thomas Beiseker, a banker instrumental in settlement of this district.

43.7 Junction. Gravel road north, Provincial Highway No. 21, leads to Acme, Three Hills, Trochu and Alix.

43.7 to 74.8 Route leads east, located on divide between east-flowing trunk streams of Rosebud Creek on south, Kneehills Creek on north.

47.5 Junction. Bircham about five miles north.

East — Two morainal ridges aligned approximately on north-south trends.

49.5 Road transects northwesterly trending esker. This sub-glacial stream deposit is well exposed on south side of road. In lower part of exposure are waterlaid sands and gravels containing pebbles of igneous and metamorphic rock derived from Precambrian Shield 700 miles northeast of here. Pebbles of sedimentary rock are derived from strata planed from Manitoba, Saskatchewan and east-central Alberta by Laurentide glacier. Waterlaid material is overlain by several feet of till with large erratics of sedimentary rock, probably deposited during ablation of continental glacier, (See Fig. 2).

59.6 Junction. Gravel road, Highway No. 26, leads eight miles north to Carbon. Name taken from coal mines in Edmonton formation located in its vicinty. Carbon gas field discovered in 1957, with 54 feet net pay in Glauconitic sand of Lower Cretaceous Blairmore formation, is located a few miles east of Carbon.

62.0 South — Wintering Hills (3,400 feet), in distance, are carved in eastward salient of Paskapoo sandstone.

63.3 Road outcrop, Paskapoo sandstone.

63.4 North — Outcrop in east side of valley of light grey sandstone with overlying dark shale. Kneehill Tuff bed in shale marks uppermost strata of Middle Edmonton member.

63.8 Bridge over small misfit stream, occupying site of Pleistocene spillway. Glacial ice, standing in lower part of Kneehills Creek Valley directly north, diverted water over present divide on which route is located into Rosebud Creek Valley south of the road; local proglacial lake occupied upper part of Rosebud Creek Valley.

64.9 Crossroad, Redland six miles south.

65.1 Road outcrop, orange-buff Paskapoo sandstone in outlier, overlying grey Edmonton sandstone in wall of Atusis Creek Valley, site of Pleistocene spillway.

67.4 South — Road leads six miles to Rosebud.

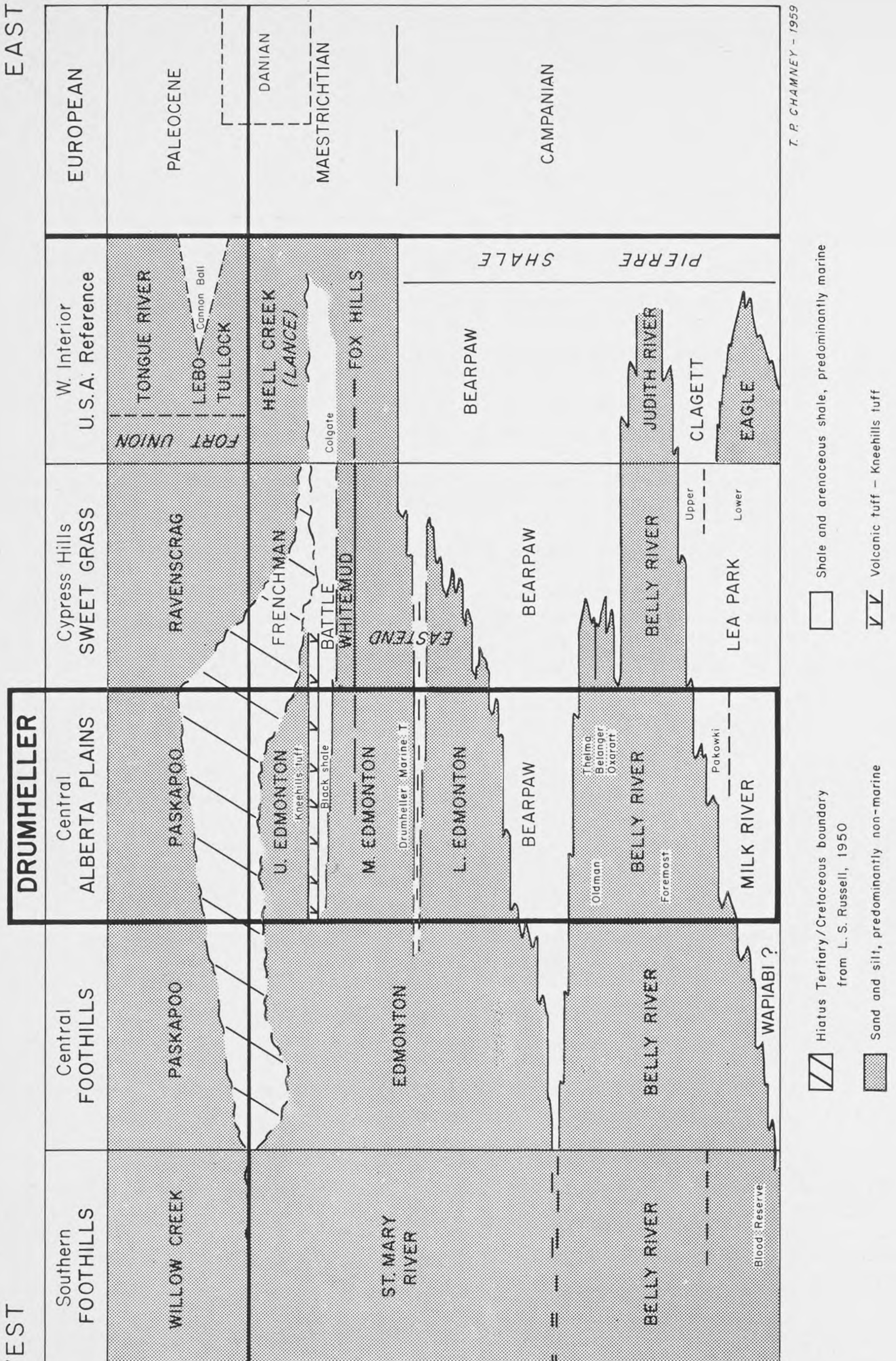
69.0 Approximate eastern erosional limit of Paskapoo formation. Route east of here is underlain by Middle and Lower member of Edmonton formation.

71.5 North — Provincial experimental agricultural plots.

72.8 Horseshoe Canyon Viewpoint on north side of Highway. Turn-off, parking and picnic areas, (See Fig. 3).

Canyon forms west side of 'horseshoe'; toe of 'shoe' is on Kneehills Creek three miles north; east side of 'shoe' is in second canyon, one mile east. The deeper canyons have their intermediate ridges disected by lateral ravines which meet and form buttes and knolls that in turn weather into haystacks or sugar-loaf mounds that are being constantly reduced by rain, frost and wind — as a consequence there is a labyrinth of intricate gorges, buttes, towers and tablelands strewn with travelled boulders and masses of ironstone which have withstood the disintegrating action of the elements. (For geomorphology see paper by Broscoe and Barton in this book).

From level of parking area to floor of Kneehills Creek Valley, erosion has cut down about 500 feet and exposed all of Middle Edmonton member and uppermost beds of Lower Edmonton member. Delineation of these members is based on two marker beds:



Tertiary — Upper Cretaceous stratigraphic nomenclature and correlation guide.

FIGURE 5

1. Drumheller Marine Tongue: This tongue, identified by locally abundant fossil oysters (Ostrea sp.), occurs at top of Lower Edmonton member. The oyster bed is exposed at floor of canyon near its junction with Kneehills Creek.

2. Kneehills Tuff Bed: This marker, rarely over eight inches thick, delineates upper boundary of Middle Edmonton member. The Tuff bed occurs within a black shale unit and caps pinnacles within canyon. Fragments of light grey tuff are abundant along rim of canyon.

Typical Edmonton stratigraphy of Drumheller area and correlations to other areas are shown in Figure 5.

78.2 Vantage point. Northeast — Deeply incised channel of Red Deer River in foreground; in background Hand Hills (3,500 feet), most prominent topographic elevation on the Plains. Hand Hills is an outlier of Paskapoo strata with resistant cap consisting of 300 feet of Oligocene (?) marl, and chatter-marked, cobble conglomerate.

79.8 Road trends north-northeast and descends along gully to Drumheller. Scattered outcrops in gully on east and west sides of road.

80.9 East — Drumheller Tourist sign. Transmission mast Drumheller Radio Station CJVB.

81.1 East — Road leads to Drumheller Golf Club.

81.3 West — Outcrop in bank, Pleistocene varved lake clays, (See Fig. 9).

81.4 West — Paskapoo formation, chiefly soft, grey to buff, clayey sandstones, soft shale and clays slightly indurated; thick, buff-weathering sandstone in lower part; contact with underlying grey beds of Middle Edmonton member is disconformable at this locality.

81.5 West — Approximate position, disconformable contact of Paskapoo and underlying Edmonton formation.

81.5 to 83.0 Road outcrop, Middle Edmonton member. At this locality member is overlain disconformably by Paskapoo formation and is underlain conformably by Lower Edmonton member exposed in floor of Red Deer River Valley.

81.6 East — Small reverse fault in Middle Edmonton member, (See Fig. 4).

81.8 West — Parking area at base of hill.

82.6 East — Thin coal seam exposed.

82.9 Junction: Highway Nos. 9 and 10. Highway No. 10 leads eastward to East Coulee and **forms route of Road Log No. 1A;** Edmonton — Bearpaw contact exposed in 'Hoodoos' at mile 9.4 of route, (See Fig. 6).

83.0 Railroad crossing on northeast limits of Drumheller.

Drumheller. Named after Samuel Drumheller who conceived the idea of forming townsite in 1910; incorporated as a town in 1916, and as a city in April, 1930. Canadian National Railway came to Drumheller in 1912, Canadian Pacific Railway in 1924. Population in 1959 is about 6,000.

Business centre is located two blocks north and west from the railroad crossing; Drumheller Civic Centre with arena, park, and museum, is directly west of north end of street ahead. Museum contains fine fossil specimens collected locally and is open to public.

Drumheller is centre of coal mining industry in Red Deer Valley which in 1946 had 24 collieries in operation. Although collieries are mostly abandoned in 1959, oil and natural gas, locally derived, are new additions to natural resources of this district.

The city is gateway to Canada's 'Dinosaur Trail' **(See circuit route of Road Logs No. 2 and 2A, and Photomosiac in back-pocket).**

ROAD LOG NO. 1A: JUNCTION HIGHWAYS NOS. 9 AND 10 TO WILLOW CREEK

This branch route, 10 miles long, leads eastward from the junction of Highways Nos. 9 and 10, which is mile 82.9 of Road Log No. 1, to Willow Creek. Lower Edmonton strata are exposed in the bluffs along the road and the contact of the Edmonton formation with the underlying transition beds of the Bearpaw formation is excellently exposed in the 'Hoodoos' near Willow Creek.

Mile

0.0 Junction Highways Nos. 9 and 10, continue east on No. 10.

0.0 to 9.0 Buttes and bluffs are eroded mostly in Lower Edmonton member.

FIGURE 6

Hoodoos at mile 9.4, Road Log No. 1A, showing formational contact of white weathering basal sandstones of the Edmonton with underlying transitional sand and shales of Bearpaw. Photograph by W. G. Murray.

3.6 North — Aerial bucket and anchor mast at tailing dump of coal mine at Plains level on north bank.

4.0 Rosedale station. Extensive terrace mid-way up bluff on north side of river marks former level (pre-Pleistocene?) of Red Deer River.

4.2 Junction, turn north. Branch road south leads 4 miles to Wayne. Wayne oil field located 5 miles southwest of Wayne was discovered in 1954 by Great Plains et al Wayne A-6-22 (Lsd. 6, Sec. 22, Twp. 27, Rge. 20, W4M.) in Blairmore Basal Quartz (See paper by Erickson and Crewson in this book).

4.3 Bridge crossing Rosebud River, confluence with Red Deer River directly north.

4.4 Railway crossing. Route ascends to former terrace level of Red Deer River.

4.6 Surficial mantle of inronstone residuum gives red colouration to rocks.

6.4 Bridge crossing Red Deer River.

9.3 Railway crossing.

9.4 North — Roadside outcrop, contact of Edmonton white-weathering sandstone with transition beds of Bearpaw formation exposed at base of 'Hoodoos' (See Fig. 6).

9.6 North — Turnoff on dirt road located on west bank of Willow Creek provides access to Bearpaw and Lower Edmonton beds remote from 'Hoodoos' selected at mile 9.4 as tourist attraction. Highway No. 10 extends only a few miles beyond Willow Creek Bridge to East Coulee.

ROAD LOG NO. 2: DINOSAUR TRAIL (CIRCULAR ROUTE) DRUMHELLER RETURN

(See Photomosaic with route appended, in back-pocket)

The route is located on the south bank of the deeply incised Red Deer River Valley. Directly north of the bridge over Ghost Pine Creek the route ascends to Plains' level at Orkney Hill and thence descends to cross the Red Deer River at either Munson Ferry (Road Log No. 2A) or at the bridge located at Morrin Ferry. Excellent panoramic views of the Badlands are provided by many vantage points. Several valley exposures permit examination of the Pleistocene, Paskapoo and Edmonton sediments. Both invertebrate and vertebrate fossils can be observed.

Mile:

0.0 Railroad crossing, southwest outskirts of Drumheller.

0.3 North — Abandoned mine on north bank of Red Deer River.

0.8 Passing through village of Newcastle formerly populated by miners and families.

1.7 Kneehill, nearly abandoned coal mining settlement.

1.8 Railway crossing. Railway crosses bridge over Red Deer River and ascends gully of Fox Creek directly north. Old coal mining village of Midlandvale situated on north bank directly east of railroad.

2.0 South — Numerous slumps in valley wall depict manner of erosion common in the Badlands.

2.4 Railway crossing. South — Tipple of abandoned coal mine and slack pile, stark monuments to once flourishing local mining industry.

3.1 Town of Nacmine, derives its name from **N**orth **A**merican **C**ollieries **Mine.**

3.5 South — Entrance to Red Deer Valley Coal Company property, (See Fig. 7.). Coal is mined from No. 1, "Deep" or "Drumheller," seam which lies about 800 feet below surface, the mine being entered by shaft; seam varies from 5 to 6 feet in thickness, divided into two benches by band of bentonite from a fraction to 20 inches thick; seam mined by room-and-pillar system; about 200,000 tons a year removed in mid 1940's.

3.6 Railway crossing.

3.7 Fork in road, keep north. Lower and Middle Edmonton strata exposed in bluffs.

4.0 North — Isolated buttes of Edmonton formation capped by resistant sandstones. 'Little Church,' miniature structure, a tourist attraction can be seen on north bank.

4.4 Coal seam exposed at roadside.

4.6 Good view of Badlands across river.

5.0 Railway crossing.

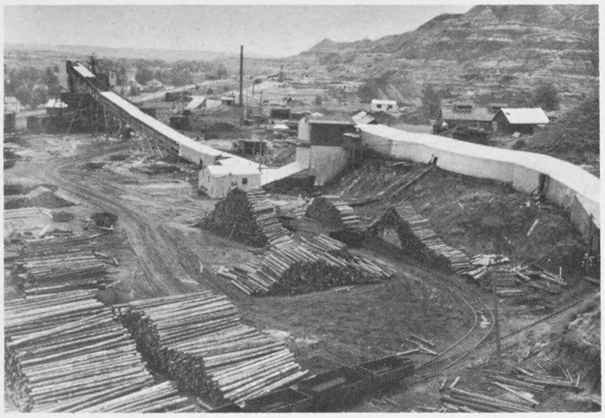


FIGURE 7 — Red Deer Valley Colliery at mile 3.5, Road Log No. 2. Shaft head in centre of photograph, tipple in upper left. Photograph by D. Knight.

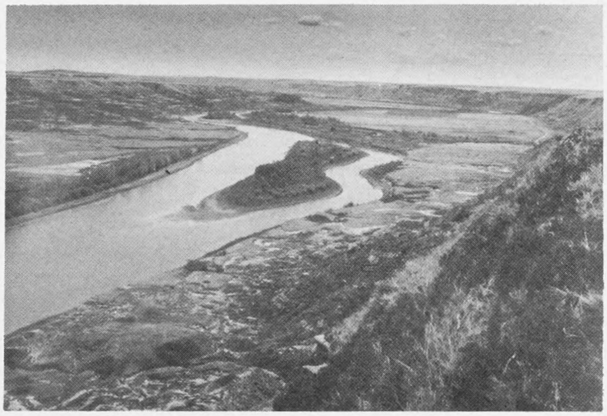


FIGURE 8 — Deeply incised south reach of Red Deer River from Orkney Hills Viewpoint, mile 11.2, Road Log No. 2. Photograph by D. Knight.

FIGURE 9 — Varved glacial lake clays, mile 46.5, Road Log No. 2, (also mile 81.3, Road Log No. 1). Photograph by D. Knight.

5.5	North — Massive buff sandstones of Paskapoo formation form cap rock in valley walls. Paskapoo rests unconformably on Middle Edmonton member.
6.3	Fork in road, keep north.
6.5	Bridge crossing Kneehills Creek. 'Toe of "Horseshoe" canyon' (See mile 72.8 of Road Log No. 1) is two miles up this creek. Uppermost Lower Edmonton strata exposed in floor of creek; Middle Edmonton member overlain by Paskapoo formation exposed in walls of creek valley.
6.9	North — West Drumheller oil field located on Plains' level across river. (See comment mile 11.2 and paper by M. R. Roop in this book).
	South — Face of bluff shows slump, mud-flow, and ironstone residuum.
7.9 to 8.2	Roadside outcrop, white-weathering bentonitic sandstone with cross-bedding and bands of ironstone concretions.
8.5	Roadside outcrop, one foot thick coal seam.
9.6	West — Contact of Tertiary Paskapoo-Cretaceous Edmonton visible at base of massive sandstone near top of cliff.
9.7	North — Erosional remnants of river terrace gravels form rounded knobs on valley floor.
9.9	Bridge crossing Ghost Pine Creek. Road ascent to Plains' level directly north from bridge. Good exposures of Lower and Middle Edmonton at roadside.
10.0	Glacial erratics resting on Edmonton strata have rolled down from till at Plains' level.
11.0 to 25.6	Gently rolling prairie, mantled with glacial lake deposits; note striking contrast of physiography with steep-sided, barren Badlands of the entrenched Red Deer River and Ghost Pine and Three Hills Creeks.
11.2	East — Orkney Hill Viewpoint, follow fence line about 500 feet. Elevation at Plains' level is about 2,600 feet, at valley bottom, about 2,200 feet.
	North from Viewpoint — Red Deer River rises in Rocky Mountains about 70 miles southwest from the city of Red Deer; it flows east from Red Deer and at a point a few miles south from Nevis the river bends sharply 90 degrees and flows south. A magnificent view of this south-southeast trending reach, almost sixty miles long, can be observed at this vantage point. A few miles south from here (See Fig. 8), the river changes course to southeast and keeps this direction almost to its confluence with South Saskatchewan River at the Alberta border.
	East from Viewpoint — Westernmost wellsites of West Drumheller oil field can be seen on benches in west wall of valley. (See photograph, Fig. 1, included in paper by M. R. Roop in this book). Nisku (D2) oil was discovered in West Drumheller field in September, 1952; Leduc (D3) oil was discovered in September, 1953. In 1959, 67 wells produced from Nisku, 12 from Leduc. Production was about 50 barrels of oil per day per wall, gravity of oil is about 42° A.P.I.
12.4	Junction. Turn west for two miles on road to Morrin Ferry (and Three Hills). Road north leads two miles to Munson Ferry **(See Road Log No. 2A).**
14.5	Turn north for two miles.
	Southwest — Incised valleys at confluence of Three Hills and Ghost Pine Creeks.
16.5	Turn west for one mile.
17.5	Turn north for five miles.
21.8	West — Wellhead, South Brazeau Fleetwood Emjay No. 1 (Lsd. 9, Sec. 12, Twp. 31, Rge. 22 W4M.), oil well producing from Mississippian Pekisko formation, completed May, 1953. Two miles west and northwest from this site are Sun Oil Company Pine wells, each of which produce oil and gas from Lower Cretaceous Basal Quartz sandstone.
22.7	Junction. Turn east on road to Morrin Ferry. Road west leads 15 miles to Three Hills.
23.1	North — Bay Coulee with outcrops of Paskapoo sandstone which contains Paleocene brackish water molluscan fauna near base of formation.
24.7	Road descends gulley to Morrin Ferry and bridge.
25.6	Road outcrop, Paskapoo formation, here overlies Middle Edmonton member. Directly up valley Paskapoo overlies beds above Kneehills Tuff, hence Upper Edmonton member.

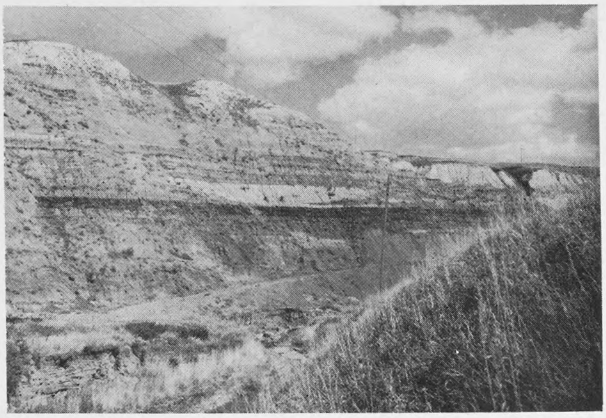


FIGURE 10 — Channel sand overlying coal seam, mile 47.9, Road Log No. 2. Photograph by D. Knight.

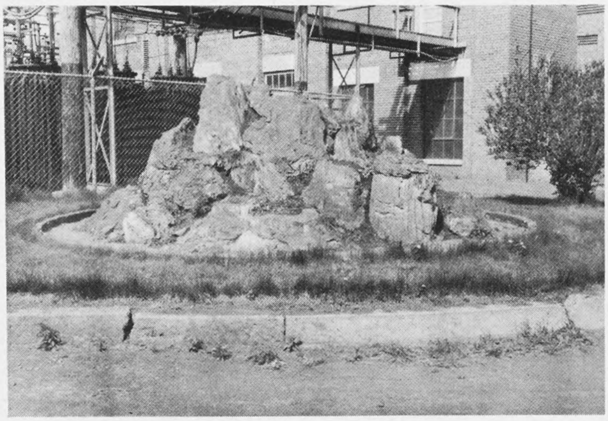


FIGURE 11 — Segments of Upper Cretaceous fossil trees, mile 49.1, Road Log No. 2. Photograph by D. Knight.

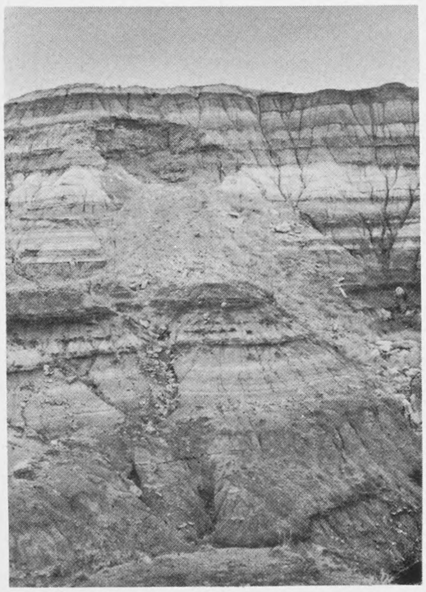


FIGURE 12 — Quarry from which dinosaur, **Edmontosaurus** was exhumed in 1957; mile 1.8, Road Log No. 2A. Photograph by D. Knight.

26.1 to 26.4 North — Road outcrop, mostly massive slump blocks with orange-weathering bed containing abundant fossil oyster (Ostrea and Corbicula sp.). This fossil bed, in place half-way up canyon wall, demarcates contact of Lower and Middle Edmonton formations.

27.0 North — Outcrop of Lower Edmonton beds with fossil bone, wood and sequoia cones.

27.1 Junction, road south leads about 7 miles to Munson Ferry.

27.2 Bridge crossing Red Deer River erected in 1958-59. Morrin Ferry House directly south. Lower contact of the Edmonton formation with marine shales of Bearpaw formation is thought to be at level of river bottom. Stratigraphic interval from this level to that of the oyster beds in canyon walls is about 500 feet, and is one of the thickest sections of Lower Edmonton member exposed on Red Deer River.

27.7 North — Uppermost exposure in bluff is dark-weathering and buff-weathering sandstones of basal Paskapoo formation.

28.0 Plains' level, east bank Red Deer River.

28.4 to 36.6 Subdued knob and kettle morainal topography with central depression prairie mounds, partly mantled by Pleistocene lake sediments (See paper by Broscoe and Barton, this book.).

29.5 Turn south for one-half mile.

30.0 Turn east for six miles to Highway No. 9.

33.1 Northeast — Marked change in relief north from Morrin marks edge of moraine.

34.2 Junction. Morrin one-mile north.

34.8 Railway crossing. Canadian National Railway from Drumheller and Kneehill to Stettler.

36.3 Junction. Turn south. Road north leads about 40 miles to Stettler; road east leads 35 miles to Hanna; road south leads 13 miles to Drumheller.

36.5 Junction with Highway No. 9, continue south. Route to Drumheller is underlain by Pleistocene lake deposits which mask buried morainal material.

38.7 East — Hand Hills (3,500 feet) most prominent topographic elevation on the Plains. Hand Hills is an outlier of Paskapoo strata with resistant cap consisting of 300 feet of Oligocene (?) marl, and chatter-marked cobble conglomerate.

40.6 Railway crossing.

42.3 Railway crossing and junction with road leading west to Munson and Munson Ferry. This is a terminal point, mile 6.7, of Road Log No. 2A.

46.5 East — Road outcrop, varved glacial lake beds at head of draw leading down to Drumheller, (See Fig. 9).

46.8 to 49.1 Roadside outcrop, Edmonton formation.

47.1 East — Two feet thick coal seam exposed.

47.9 East — Excellent profile of Cretaceous channel sand; planoconvex lens of white-weathering bentonitic sandstone directly above coal seam, (See Fig. 10). Coal seam apparently correlates with seam located directly north, but 50 feet higher. Displacement may reflect fault or slumping.

48.3 East — Bentonite mine. Bentonite, a clay mineral which has been derived from alteration of volcanic ash, is used in the manufacture of drilling mud for oil wells.

48.6 Bridge crossing coulee of Michichi Creek. Mine at head of coulee worked the No. 7, "Vulcan" or "Daly," coal seam.

East — Drumheller oil field is located at Plains' level, two miles east of here. Thirteen wells produced 33.2 A.P.I. oil from two pools in the Devonian Nisku formation at a rate of 75 barrels per day in early 1959; and three wells produce 31.5 A.P.I. oil from the Lower Cretaceous Basal Quartz sand at a similar rate. (See paper by M. R. Roop, this book).

49.1 Bridge crossing Red Deer River, erected 1958-59.

East — Canadian Utilities Limited steam-electric plant. Several fine specimens of fossil trees located on plant lawn, (See Fig. 11). Drumheller Community Centre and Museum directly east of electric plant.

TABLE OF FORMATIONS
ROCKY MOUNTAIN FRONT RANGES AND FOOTHILLS, MOOSE MTN. AREA

AGE	GROUP & FORMATION		DESCRIPTION	THICKNESS	
				FRONT RGE.	FOOTHILLS
QUATERNARY			DEPOSITS OF TILL AND GRAVEL, LARGELY CONFINED TO VALLEYS OF MAJOR STREAMS.		
PALEOCENE		PASKAPOO	SHALE AND BUFF SANDSTONE. NON-MARINE.		2,000 +
UPPER CRETACEOUS		BELLY RIVER	PALE GREENISH GREY SANDSTONE AND GREENISH SHALES. CONGLOMERATE AND COAL SEAMS IN LOWER PART. NON-MARINE.	4,000 ?	1,500 +
	COLORADO GROUP	WAPIABI	NODULAR SANDY SHALE AND DARK, PLATY SHALE, WITH MINOR THIN SANDSTONE BEDS. MARINE.	1,500	1,775
		CARDIUM	RUSTY WEATHERING QUARTZOSE SANDSTONE WITH PEBBLE CONGLOMERATE INTERBEDDED WITH RUSTY, SANDY SHALE. MARINE.	600	200-265
		BLACKSTONE	BLACK, FISSILE SHALE WITH A FEW THIN BEDS OF SANDSTONE. MAKINE.	800 ±	700-800
LOWER CRETACEOUS		BLAIRMORE	GREENISH GREY SANDSTONE INTERBEDDED WITH GREEN AND MAROON, CRUMBLY SHALES, CONGLOMERATE, AND MINOR COAL. LIMESTONE BEDS NEAR MIDDLE; MASSIVE PEBBLE CONGLOMERATE AT BASE. NON-MARINE.	2,500±	2,000-2,300
		KOOTENAY	FINE, DARK GREY SANDSTONE, CARBONACEOUS SHALE, AND COAL SEAMS. NON-MARINE.	2,000-3,500	200-350
JURASSIC		FERNIE	BLACK, NODULAR SHALE AND PHOSPHATIC SHALE, AND MINOR DARK LIMESTONE OVERLAIN BY BROWN, SANDY SHALE AND THIN SANDS.	1,100±	200-250
TRIASSIC		SPRAY RIVER	DARK, REDDISH-BROWN, SHALY SILTSTONE AND DARK BROWN, SILTY SHALE, MARINE.	1,000±	0
PERMIAN (?)		ROCKY MOUNTAIN	CHERTZITE, DOLOMITIC FINE SANDSTONE AND SANDY DOLOMITE.	200-400	0
MISSISSIPPIAN	RUNDLE	TUNNEL MOUNTAIN	GRAY LIMESTONE, DARK DOLOMITE, CHERT. GREEN SHALE.	1,500-1,700	0
		MOUNT HEAD	SILTY, CHERTY, DENSE DOLOMITE AND BRECCIA.		550±
		TURNER VALLEY	FRAGMENTAL LIMESTONE AND DOLOMITE.		300-400
	BANFF	SHUNDA	SILTY, CRYPTOCRYSTALLINE DOLOMITE AND BRECCIA.	950-1350	150-250
		PEKISKO	LIGHT GREY FRAGMENTAL LIMESTONE.		300-350
			CALCAREOUS SHALE, ARGILLACEOUS CHERTY LIMESTONE.		150-300
		EXSHAW	BLACK ARGILLACEOUS LIMESTONE AND BLACK PLATY NON-CALCAREOUS SHALE.	60-90	30 ±
UPPER DEVONIAN		PALLISER	DOLOMITE AND LIMESTONE, DARK TO BROWNISH GREY, MICROCRYSTALLINE, THICK BEDDED.	800-900	700-800
		ALEXO	ARGILLACEOUS, SILTY DOLOMITE WITH DOLOMITIC SILTSTONE, RED AND GREEN MUDSTONE.	100-300	100 ±
	FAIRHOLME	SOUTHESK	MASSIVE, COARSE LIGHT GREY DOLOMITE.	150-250	150-250
			THICK BEDDED, DARK ARGILLACEOUS DOLOMITE.	50-150	50-150
			THICK BEDDED, COARSE, LIGHT GREY VUGGY DOLOMITE	200 ±	200 ±
		CAIRN	DARK GREY AND BROWNISH GREY DOLOMITE WITH ORGANIC STRUCTURES WITH LATERAL TRANSITION TO DOLOMITE INTERBEDDED WITH DARK BROWN SHALE.	450-550	500 ±
UPPER (?) DEVONIAN		GHOST RIVER	LIMESTONE BRECCIA AND GREY ARGILLACEOUS DOLOMITE.	6-30	140
UPPER CAMBRIAN			GREEN AND RED DOLOMITIC SHALE.	25-195	
MIDDLE CAMBRIAN		C* (MODIFIED)	MEDIUM TO FINE GRAINED, BLACK AND GREY LIMESTONE AND DOLOMITIC LIMESTONE.	1,000±	350 ±
		B*	ALTERNATING BEDS OF DENSE BLACK LIMESTONE AND GREY OOLITIC LIMESTONE.		629
		A*	GREEN SHALE WITH THIN BEDS OF BROWN, OOLITIC AND GLAUCONITIC LIMESTONE.	1,600+ (?)	1,570 +

COMPILED FROM: H. H. BEACH*(1943); L. M. CLARK (1949); R. deWIT (1956); H. BELYEA (1956); P.F. MOORE (1958) AND OTHERS

FIGURE 13

ROAD LOG NO. 2A: MILE 12.4 OF ROAD LOG NO. 2 TO MUNSON FERRY AND HIGHWAY NO. 9

This branch route, 6.7 miles long, permits examination of Pleistocene, Palaeocene and Cretaceous sediments. Fossil bone beds and fossil vertebrate quarry are located near the mid-point of the route.

Mile:

0.0 Junction. Follow road north leading 1½ miles to Munson Ferry. Road south and west is route of Road Log No. 2, mile 12.4.

0.5 Junction, road east leads down gulley to valley floor and Munson Ferry, use low gear.

South — Outcrop, bedded Pleistocene lake sediments, note varved characteristics and colour and size gradations and alterations.

0.6 South — Outcrop, orange-buff sandstone of Paleocene Paskapoo formation. This unit caps the Plains west from here to Rocky Mountain Foothills.

0.7 North — Vertebrate shaft bone (femure?) is exposed in massive sandstone of the Paskapoo formation directly above roadside.

0.8 Approximate position of Tertiary Paskapoo-Cretaceous Edmonton contact.

1.0 North — Outcrop above road, orange-weathering oyster bed at contact of Lower and Middle Edmonton members.

1.3 Southeast — Road leads to picnic and camp grounds.

1.8 Munson Ferry House, known also as Bleriot Ferry, named after brother of first man to fly the English Channel, who had a cattle ranch at this point.
Branch road north leads about one mile to Dinosaur Bone Bed located about halfway up the bluff in Lower Edmonton member. All the bones are disjointed, most are fragmented; teeth and armoured scutes are present. Articulated skeletons of vertebrates are rarely found associated with Bone Beds. A walk of about one-quarter of a mile north from the Bone Bed brings one directly below Dinosaur quarry which can be observed in upper part of bluff. The Canadian National Museum, Ottawa, removed a large vertebrate specimen, "Edmontosaurus," from this quarry in 1957, (See Fig. 12). Over 20 tons of rock was hand-picked from the quarry; the rock encased specimen weighed over one ton. A duck-billed dinosaur was quarried from a site across the river by Levi Sternberg in 1912, (See paper by Dr. Wann Langston in this book).

2.0 East bank, Red Deer River, 2,250 feet.

2.7 to 6.7 Plains' level, 2,600 feet. Glacial lake sediments mantle Edmonton bedrock.

4.7 Road south leads to West Drumheller oil field tank batteries; oil is shipped by railway tank car and pipeline.

6.2 Munson.

6.7 Junction with Highway No. 9. This is mile 42.3 of circuit route, Drumheller return, Road Log No. 2.

FIELD TRIP NO. 2 — (MOOSE MOUNTAIN AREA), FOOTHILLS AND FRONT RANGES

(See Fig. 1 and geologic compilation maps in back-pocket)

ROAD LOG NO. 1: TRANS-CANADA HIGHWAY, CALGARY TO BANFF

The route traverses the western Plains, the Rocky Mountain Foothills and Front Ranges. Along the route there are exposed sequences of rock formations representative of most of the geologic time-scale, Middle Cambrian to Eocene. (See Fig. 13). Many grand Front Range structures are displayed.

Mile:

0.0 East abutment Trans-Canada Highway bridge crossing the Bow River in southwest Calgary. First 14.3 miles of route are underlain by early Tertiary Paskapoo formation located in east flank of Alberta syncline on western margin of Plains. This flank is part of extensive homocline which dips gently southwest from Precambrian Shield, 700 miles northeast.

0.3 Underpass, Canadian Pacific Railway.

2.2 North — Branch road to Bowness town centre.

4.0	South — Station CHCT-TV television transmitter tower.
4.7	Crossroad.
5.0	Hilltop Viewpoint. North — Several abandoned terrace levels indicating past elevations of Bow River.
	West — Foothills ridges and Front Ranges of Rocky Mountains.
	Northwest — Devil's Thumb, a dark 9,174 foot beehive-like peak on skyline of Rocky Mountains; peak is capped by klippe of Middle Cambrian limestone.
6.0	Crossroad. Junction old Banff coach road.
6.5	Northwest — West-facing bluff visible in distance on skyline is formed by east-dipping Paskapoo sandstones and shales in west limb of Alberta syncline; bluff marks approximate western boundary of Plains; west of bluff are the Wildcat Hills of the eastern Foothills. Below and east of bluff is Cochrane Viewpoint on old Banff Trail, a stop on earlier field trips.
7.2	Hilltop Viewpoint. Foothills ridges in middle ground; Rocky Mountain Front Ranges on skyline.
10.7	Crossroad and cattle underpass.
12.3	Hillside Viewpoint: South — Physiographic provinces evident, east to west, Plains, Foothills, and Front Ranges of the Rocky Mountains.
12.8	Crossroad. Road north leads 7 miles to Cochrane; road to south leads 12 miles to Bragg Creek **and along route of Road Log No. 2.**
14.3	West side of Towers Ridge, approximate position of contact of Paskapoo and Edmonton formations. The Paskapoo formation forms Towers Ridge in western margin of Plains; Edmonton formation is cut by fault in easternmost Foothills.
16.2	Bridge crossing Jumpingpound Creek. Wapiabi shales are exposed in downstream cutbanks. Cardium sandstone is exposed in cutbank on east side of creek directly upstream from bridge. These outcrops are in east limb of an asymmetric fold, known as the Jumpingpound structure; fold is underlain by the Jumpingpound thrust and is broken by subsidiary faults. The Jumpingpound thrust separates this shallow structure from an underlying fault slice containing a Palaeozoic core which is the producing reservoir of Jumpingpound wet-gas field.
16.2 to 24.5	Route follows a westward and northwesterly course crossing obliquely a succession of north-northwest striking faults which thrust Colorado over Belly River strata; Belly River sandstones form sub-parallel strike ridges separated by valleys eroded in Colorado shales, typical of Outer Foothills topography.
17.5	Road outcrop, Belly River sandstones and shales.
	North — Nicoll Ridge formed by Belly River sandstone; Wapiabi shales are thrust over Belly River along a fault on west side of ridge.
18.7	Road outcrops, Belly River sandstones and shales.
	South — Bateman Ridge formed by Belly River strata; Wapiabi shales are thrust over Belly River along a fault on west side of ridge.
19.0	Underpass, on west-facing hillside.
19.1	Road junction: South — Road leads to Jumpingpound Ranger Station. Junction is mile 38.2, the termination of Road Log No. 3.
20.9	Cattle underpass. Northeast — View down Pile-of-Bones Creek Valley; Shell Oil's Jumpingpound Gas and Sulphur Plant is visible in the distance.
21.4	Road outcrop, Belly River sandstones and shales forming Noble Ridge; Blackstone shales are thrust over Belly River along fault on west side of ridge.
22.3	Road outcrop, Wapiabi shales with ironstone concretions.
22.5	Roadfill, crossing Sibbald Lake.
23.3	Road outcrop, Wapiabi shale.
24.5	Road outcrop, Belly River sandstone in foot wall of Outwest fault; Outwest fault, traced southward to Turner Valley area, is sole fault of Highwood uplift.
	South — Livingstone Ridge formed by Belly River strata. Route, for next 6.3 miles, crosses Colorado strata repeated by thrust faults.
25.5	East Boundary Stony Indian Reserve: Stonies or Mountain Assiniboines are an isolated offshoot of Assiniboine tribe which inhabited Plains of Saskatchewan and Manitoba. They occupied a limited area on flanks of Rocky Mountains south of Yellowhead Pass.

27.3 Road outcrop, Wapiabi shale.

27.5 Road underpass.

28.3 Road outcrop, Wapiabi shale.

30.8 Crossroad — Road north leads one mile to Morley Village. In 1872 Methodist Missionary George McDougall built the little log church that still stands on the north side of the Bow River and began a mission to the Stony Indians. He was aided in construction of the church by John Sibbald, who also opened a school (Sibbald Creek, Sibbald Lake and Sibbald Flat are named after him). A small settlement known as Morleyville soon grew around the Mission. When Rev. George McDougall was frozen to death in a blizzard in 1876, his son, Rev. John McDougall, continued the Mission. In 1883 the Canadian Pacific Railroad was built on the south side of the Bow River and the Post Office was moved to the railroad, and gradually the entire settlement migrated to its present site. The old log church was abandoned in 1921, but was recently restored by the United Church and other service organizations.

30.8 to 34.2 Route crosses broad fault slice of Belly River strata, occupying a position directly east of northwest-plunging Moose Mountain dome.

33.1 Hillside viewpoint. Panorama of Rocky Mountain Front Ranges.

34.2 Route located on flood-plain terrace of Bow River.

34.2 to 41.1 Route crosses fault slices of Colorado strata on northwest-plunging end of Moose Mountain dome; high ridges 5 miles southward are held up by Blairmore strata on north flank of dome; at apex of the dome, located 18 miles southeast, are exposed strata as old as lower Banff. (See Road Log No. 2A).

40.5 Crossroad. Road north leads one mile to Seebe bridge, Kananaskis Falls, and Calgary Power's Hydro-electric Plant. This plant, completed in 1913 with an initial capacity of 12,000 horsepower, was enlarged to 24,000 horsepower in 1949. Horseshoe Plant located two miles downstream from Seebe bridge was completed in 1911, with a capacity of 20,000 horsepower. Dams at both plants are constructed on Cardium sandstone. Cardium named by D. D. Cairnes after 'Cardium pauperculum,' first collected from "type" section by Hector, geologist and physician to the Palliser expedition. Road south, the Kananaskis Forestry road, leads to Kananaskis Lakes, High River turn-off to Longview, and to Coleman in Crowsnest Pass.

Road closed

40.6 Northwest — Good view of End Mountain (7,940 feet) in first range of Rocky Mountain Front Range Sub-Province. Rusty-weathering band approximately one-third distance from base of mountain is Ghost River formation; Middle Cambrian carbonates exposed below, Upper Devonian Fairholme group crops out above. Palaeozoic strata forming mountain are folded synclinally and thrust over Upper Cretaceous Belly River beds.

41.2 Bridge crossing Kananaskis River; camp ground located at bridge approach. Cardium sandstone located on southwest flank of north-plunging Moose Mountain dome exposed in channel of Kananaskis River; route for next 2.7 miles crosses Wapiabi and Belly River in west flank of Moose Mountain dome. Tree-covered ridges directly south and east of Front Range scarp are underlain by Belly River strata.

44.1 Tourist parking area. North — Yamnuska Mountain (easternmost in panorama, Fig. 14), composed of Middle Cambrian carbonates thrust over Upper Cretaceous Belly River sandstones and shales on McConnell thrust. Middle Cambrian carbonates form precipitous cliffs of upper one-third of mountain and Belly River strata forms lower tree-covered slopes. The low angle thrust fault was recognized in 1887 by Geological Survey of Canada geologist, R. G. McConnell, after whom the fault is named. The fault or fault zone has been traced continuously from Highwood Pass northward to Wildhay River, a distance of over 250 miles. The McConnell fault, nearly horizontal beneath Yamnuska Mountain dips steeply westward under the frontal Cambrian scarp of the Fairholme Range. Throw of the fault is estimated in miles of horizontal displacement and thousands of feet of vertical displacement. The rusty weathering band directly west of the frontal scarp is Ghost River formation, which is overlain by dark grey Fairholme group forming partially tree-covered slopes; overlying massive light carbonates forming ridge descending to valley floor are strata of Palliser formation.

44.6 Road outcrop, Middle Cambrian carbonates located in hanging wall of McConnell thrust fault; outcrop visible on road in Figure 14.

North — Loder Lime Plant, quarry is in Middle Cambrian limestone.

45.2 North, across Bow River — Panoramic view of Palaeozoic sequence of Fairholme Range (East half of Fig. 14). From east to west, Middle Cambrian carbonates form cliffs of Yamnuska Mountain, overlain by rusty-weathering Ghost River formation; Ghost River formation is overlain by dark Fairholme group which forms partially tree-covered slopes; Fairholme group is here divisible into the dark stromatoporoidal dolomites of Cairn formation below and the overlying lighter carbonates of Southesk

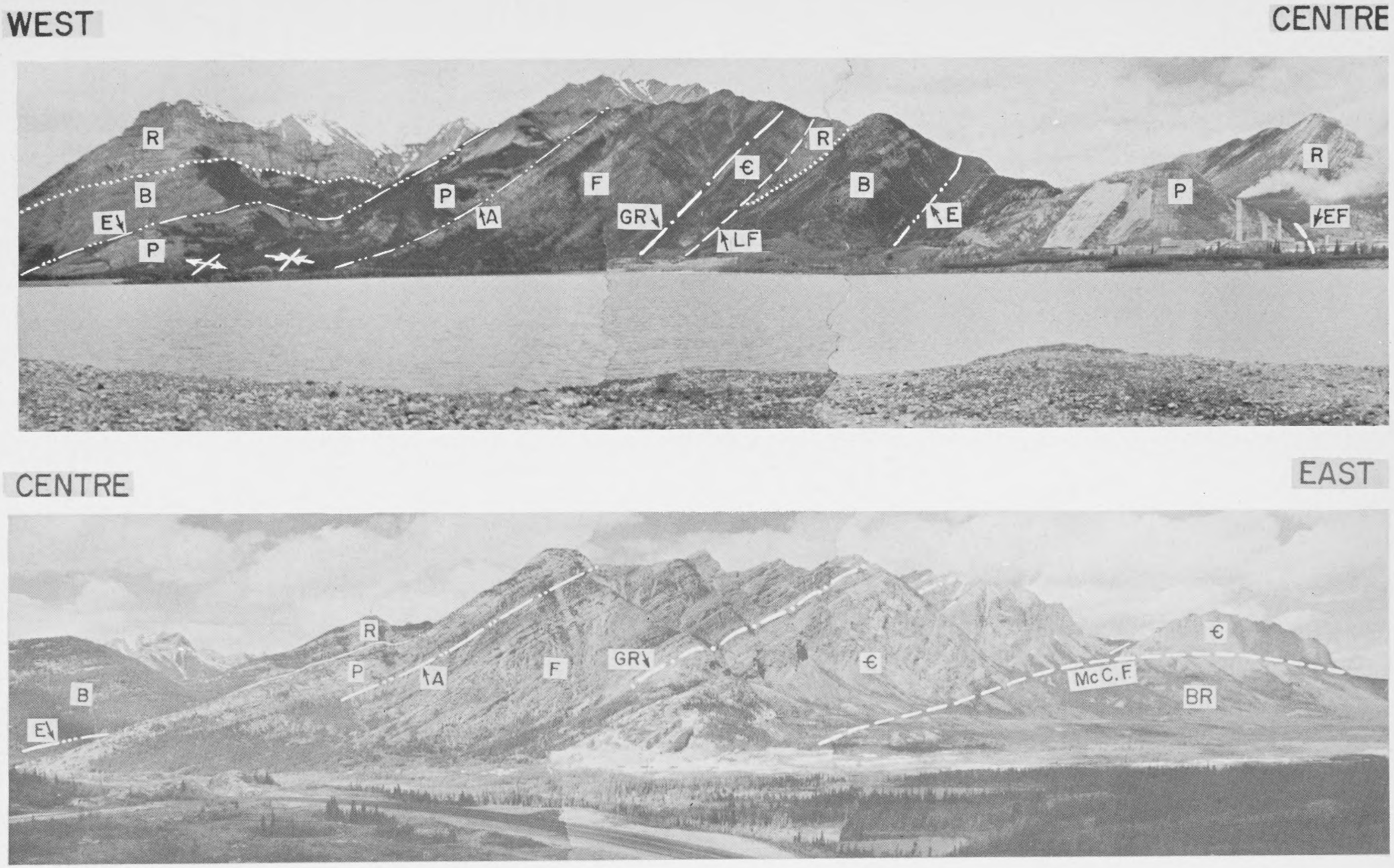


FIGURE 14

Panorama of Fairholme Range, looking north from Bow River. Grotto Mountain on the west, Canada Cement Plant in centre, Loder Lime Plant and Yamnuska Mountain on the east. Lower photograph taken near parking area at mile 44.1; upper photograph, at mile 47.4, Road Log No. 1. McConnell fault (McC.F), Exshaw fault (E.F), Lac des Arcs fault (L.F), Cambrian (C), Ghost River (GR), Fairholme (F), Alexo (A), Palliser (P), Exshaw (E), Banff (B), Rundle (R), and Belly River (BR). Annotation partly after L. M. Clark. Photographs by W. Wegmuller and R. Umiker.

formation; massive cliff of Palliser formation, dipping into valley of Jura Creek, is separated from the underlying Fairholme group by a barely discernable band of the Alexo formation. Jura Creek follows the Exshaw outcrop and is type area of the Exshaw formation. Mountain on west side of Jura Creek is formed by Mississippian strata; lower tree-covered slopes are formed by the shaley limestones of Banff formation, and upper slopes are carved in cyclically bedded Rundle carbonates.

46.5 South — Heart Mountain, composed of Rocky Mountain and Rundle strata; prominent ridge of massive Rundle strata ascending from the road to the mountain peak is located between branches of the Exshaw fault. The mountain takes its name from synclinal drag fold in the peak.

46.7 Bridge.

46.8 Road crosses trace of Exshaw fault.

47.4 Viewpoint, tourist parking area on bank of Lac des Arcs. Across lake to north is Canada Cement Plant (See west half of Fig. 14). The Palliser limestone in which the quarry is located is overlain by a sequence of Banff and lower Rundle strata, over which is thrust on the Lac des Arcs fault, a sequence of dark Cambrian limestones, rusty-weathering Ghost River formation and dark Fairholme carbonates. Road outcrop on south side of road is Banff formation in foot wall of Lac des Arcs fault.

47.5 Road crosses surface trace of the Lac des Arcs fault.

47.7 Road outcrop, Fairholme. Picnic table.

48.2 Tourist parking area. Road outcrop, Fairholme carbonates form a low ridge projecting into Lac des Arcs; note the dark band, a stromatoporoidal biostrome interbedded with the light grey coralliferous carbonates.

48.7 Road constructed on fill across embayment of Lac des Arcs; massive beds exposed along lake shore are Palliser.

Northwest — Across Bow Valley is a profile view of Grotto Mountain (Westernmost, in Fig. 14). Grotto Mountain is anticlinally folded, its peaks formed of Upper Rundle and Rocky Mountain strata, middle slopes of Banff, and lower cliffs of Palliser.

Southwest — Pigeon Mountain, strike extension of Grotto Mountain; Palliser in the lower cliffs, middle slopes of Banff, and upper cliffs of Rundle.

50.0 Bridge.

50.6 Road outcrop, Banff formation.

50.7 Road outcrop, Rundle formation.

50.9 Culvert, picnic area.

51.6 Bridge crossing Pigeon Creek. Route for next 14.7 miles follows strike valley of the Bow River, cut in broad syncline of Canmore-Cascade Coal basin; Fairholme Range on the east, Rundle Range on the west. These ranges are designated, respectively, First and Second Ranges of the Rocky Mountain Front Ranges Sub-Province. Canmore-Cascade Coal basin is a synclinal drag fold formed in foot wall of Mount Rundle fault; Mesozoic strata as young as Lower Cretaceous Blairmore are preserved in the axis of the basin.

52.0 North — Picnic and camp grounds.

53.4 West and Northwest — Rundle Range; cliffs along crest are formed by Rundle limestone; shale slopes below, with medial limestone member, are Banff formation; lower cliffs are Palliser formation, and forested slopes at base are underlain by the Fairholme group. Rundle Range exhibits a structural-physiographic profile typical of Front Ranges at this latitude.

55.0 Bridge crossing Bow River. Northwest — Road visible on south end of Mount Rundle leads through 'Whiteman's Gap' to three Calgary Power hydro-electric plants completed in 1951. Water from the Spray Lakes drainage system, located west of the Rundle Range, is diverted by a system of canals and a 2,151 foot tunnel cut in Palliser and Fairholme carbonates to drop a vertical distance of 905 feet, generating 62,000 electric horsepower in a hydro-electric plant at the foot of the scarp. An additional 21,000 horsepower is developed by two other plants before the water is released to enter the Bow River. The generating capacity of these plants will be increased to 107,000 horsepower by additions to be completed by 1959. There are excellent exposures of an Upper Devonian stromatoporoidal reef along the road ascending 'Whiteman's Gap' which is accessible from mile 57.0 of this log.

55.9 Highway overpass crossing old Calgary-Banff highway and Canadian Pacific Railway. Highway follows Bow Valley northward along strike of Canmore-Cascade Coal basin.

South — Mount Allan, formed by Mesozoic Fernie, Kootenay and basal Blairmore conglomerates, sands and shales preserved in the axis of the Canmore-Cascade Coal basin. The cut line crossing Mount Allan is the right-of-way of Calgary Power Transmission line from Kananaskis Lakes.

56.1 Turnoff, to Canmore, and old Banff-Calgary highway.

South — Three Sisters Mountain (9,744 feet); west peak in formed of Rundle limestone; two peaks on east are formed of Palliser, repeated by faulting.

57.0 Crossroads. Road south leads one mile to Canmore, and route through 'Whiteman's Gap' to Devonian reef exposures and Spray Lakes. Canmore is a coal mining town of approximately 1,200 people; coal seams, about 30 feet thick, of low volatile non-coking steam coal are mined and stripped from the Kootenay formation.

57.4 East — 'Solifluction terraces' formed on flanks of ridge; gravitational earth slide or animal trails?

58.1 Northwest — U-shaped glacial profile of Bow River Valley.

58.9 East — Canmore Ranger Station, Bow River Forest Reserve. The Forest Reserve in Alberta is administered by the Alberta Forest Service within policy set by Eastern Rockies Forest Conservation Board. The Reserve is divided into three forests: The Crowsnest Forest, the Bow River Forest and the Clearwater Forest. Each forest is subdivided into several districts in the care of a Forest Ranger and his assistants. Notwithstanding the great value of the timber, grazing, coal, oil and other resources of the Forest Reserve, the prime objective of the Conservation Board is to maintain a continuous and adequate supply of clear water from the drainage.

59.1 Junction, with old Banff-Calgary highway (A geologic road log of the old highway is available in the Guide Book of the Sixth Annual Field Conference of the A.S.P.G., 1956; the terminus of that log is at the Canmore junction on the old road; mileage 20 to 44.1 of the log is for a side trip to Shell Oil Company's Jumpingpound Gas and Sulphur Plant.)

61.2 East gate Banff National Park — Buildings are constructed of Cretaceous sandstone quarried near Anthracite. Banff is Canada's oldest and second largest National Park.

61.5 West — Cut line on forested slope of Mount Rundle (9,838 feet) defines east boundary of Banff National Park.

62.7 Bridge crossing Carrot Creek. Fluvioglacial sands and gravel in northwest bank.

65.8 East — Mount Peechee (9,625) and Mount Girouard (9,825 feet) in Fairholme Range.

"Cheminées de Fées"

66.3 Wayside tables. East — 'Hoodoos' or 'Desmoiselles,' formed by differential erosion of Alpine glacial till.

66.8 South — Branch road to 'Hoodoos' and Tunnel Mountain road.

67.2 East — Branch road to west end of Lake Minnewanka. Slack heaps are from Anthracite coal mine, now abandoned.

67.5 North — Tail race, Cascade hydro-electric plant, completed in 1942. Water from Lake Minnewanka reservoir, storage 100,000 acre-feet, drops 330 feet in two miles to generate originally 32,000 electric horsepower; the plant was modified in 1957 to generate 46,000 horsepower.

68.0 North — Cascade Mountain (9,840 feet), lower cliffs are formed of Palliser, middle band of Banff, limestone cliffs in upper third of mountain are Rundle. Cascade Mountain is structural continuation of Mount Rundle.

68.2 Road and Railway outcrop, Lower Cretaceous Kootenay sandstone, located in foot wall of Mount Rundle fault; Devonian strata is thrust over Kootenay in hanging wall of Mount Rundle fault.

68.9 Bridge crossing Cascade River.

69.3 Traffic circle: North, Lake Minniwanka; South, Banff; West, Lake Louise; East, Calgary.

69.6 North — Banff airstrip.

70.5 North — Buffalo paddocks. Here the National Parks Department has a herd of buffalo for tourist attraction; tourists' cars may enter pasture for close-up of animals via attended gate.

70.8 Bridge crossing Forty Mile Creek.

71.4 North — Road outcrop, fragmental limestones of Livingstone formation on east end of outcrop; dark limestones of Mount Head formation on west end of outcrop.

71.7 North — Road outcrop, siliceous rocks of Norquay formation of Rocky Mountain group.

71.9 Overpass — Trans-Canada highway leads west to Lake Louise, and east to Calgary. Branch road leads south to Banff and north to the "Green Spot" on Mount Norquay. An excellent view of the Banff area can be obtained from the "Green Spot." The second, third, fourth and fifth Front Ranges of the Rocky Mountains are visible; Cascade Mountain, Stoney Squaw and Tunnel Mountain are structural extensions of the Rundle Range or second Front Range; Sulphur Mountain in foreground, south of the highway, and Mount Norquay, north of the highway, make up the third Front Range; farther to the west is Bourgeau Range or fourth Front Range; and to the west, in the background, Pilot Mountain, the fifth Front Range.

ROAD LOG NO. 2: A TRAVERSE OF THE FOOTHILLS FRONT RANGE ALONG THE ELBOW AND LITTLE ELBOW RIVERS

The route of Road Log No. 2 trends southward from the Trans-Canada Highway at a point 7 miles south of Cochrane (mile 12.8 of Road Log No. 1) and crosses the west limb of the Alberta syncline to the vicinity of Bragg Creek and thence trends southwestward and traverses the Outer and Inner Foothills and eastern Rocky Mountain Front Range. Palaeozoic and Mesozoic rocks are well exposed at many excellent and accessible sections. (See Table of Formations, Fig. 13). The strata trace out many typical and complex structures, most of which are readily apparent. Several grand picnicking and camping sites are located along the route.

This road log should be used in conjunction with the structure compilation map enclosed in the back-pocket or with the Geological Survey of Canada maps noted in the reference list. Typical stratigraphic sections exposed on route are synopsized in Figures 13 and 15.

Mile:

0.0 Junction with Trans-Canada Highway, turn south. This is mile 12.8 of Road Log No. 1.

1.2 Wooden bridge crossing tributary of Pirmez Creek.

1.4 Road junction continue south. Branch road west leads to Jumpingpound Ranger Station and joins the circuit route (Road Log No. 3) to Elbow Falls.

2.1 East — Road outcrops, northeast dipping Paskapoo sandstone located in west flank of Alberta syncline.

2.4 Canadian Youth Wildwood Hostel. The first Youth Hostel in North America was started in a tent near Bragg Creek on July 1, 1933. In July, 1958, there were 50 hostels across Canada, many of which are located in the National Parks. The Canadian movement was started by Mary Barclay, principal in 1958, of Rosscarrock School, Calgary.

2.9 Route underlain by narrow belt of Edmonton strata located on west limb, Alberta syncline. Edmonton strata exposed in Drumheller area are in east limb of this regional basin.

3.3 Wooden bridge.

3.6 Bridge.

4.0 Bridge crossing Elbow River, Edmonton strata dip west in outcrop upstream. Approximate position of surface trace of Jumpingpound fault. This fault cuts at a shallow depth in Jumpingpound gas field and intersects surface rocks about one mile east of the field. The fault is considered by some geologists to be continuous with Turner Valley fault and to separate structurally, Foothills from Plains.

4.6 Road junction, continue south. Branch road east leads via Twin Bridge to Richmond Road, Calgary.

West — Gate to Camp Kiwanis.

5.5 South — Forested ridge underlain by Belly River sandstone located on axis of anticline.

6.1 North boundary of Sarcee Indian Reserve No. 145; 62,000 acres with population of about 260 Indians. Route trends southwest through northwest corner of Reserve. Northeast corner of this eastward elongate rectangular Reserve is located in southwest Calgary.

6.8 to 10.9 Route trends southwest, transverse to belt of fault slices which repeat Belly River strata.

10.9 to 11.8 Route traverses east flank of Whiskey Creek anticline; core formed in Blairmore sandstone, structure expressed in outcrop in channel of Elbow River one-quarter mile north; fore-limb cut by Outwest fault.

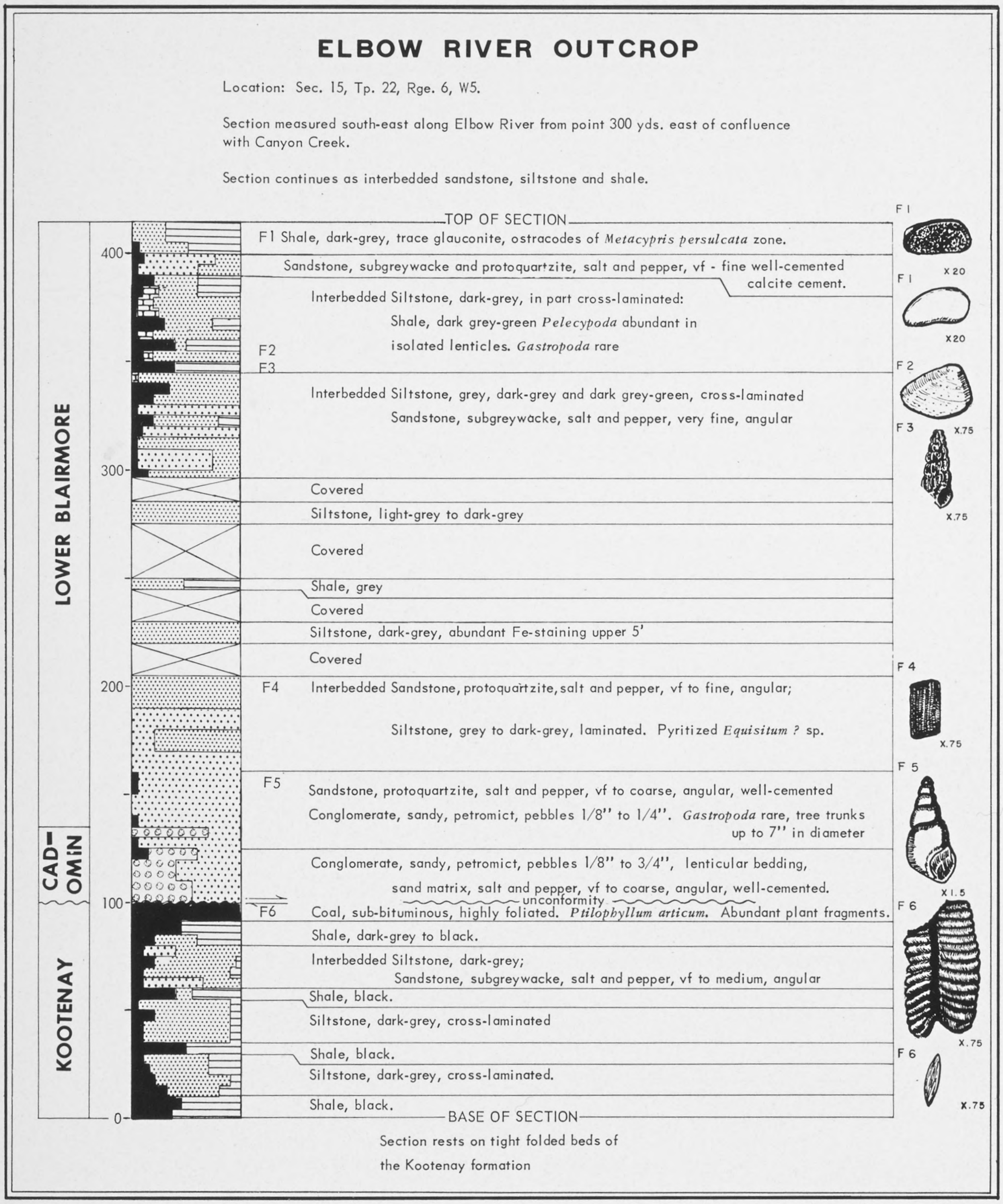


FIGURE 15

Lower Blairmore-Kootenay section, Elbow River, Moose Mt. Dome.

(after D. Loranger)

11.6	Junction, cut-off route directly south joins with mile 12.4 of this log.
11.8	Bragg Creek post office and store, elevation 4,266 feet. Bragg Creek was named after Albert W. Bragg who ranched in the district in 1882. Post Office is approximately on axis of Whiskey Creek anticline here expressed in Blairmore formation. Continue on winding road east.
12.4	Junction, road north is cut-off from mile 11.6 of this log. Logged route leads south along west boundary of Sarcee Indian Reserves and crosses obliquely south-plunging Whiskey Creek anticline (a 'tight' fold) expressed in Colorado sequence.
13.8	Culvert crossing Priddis Creek. Prominent hill directly east is Fish Butte formed in Belly River sandstones. 15 mi. to Ranger Sta. -at Sunny Slope (white ranch house). Turn right here. 6½ mi. to Elbow Falls
13.9	Junction — Logged route continues on road west which leads to Moose Mountain, Elbow Falls, and up Little Elbow River into Front Ranges. Road south leads 0.4 miles to Bar K-C Ranch and thence to Priddis and Midnapore, or Turner Valley. Junction is located on axis of Whiskey Creek (Two Pine) anticline; axis trending northwest is expressed in Blackstone shale.
14.2	Approximate surface position of Fisher Mountain fault. Blairmore underlying ridge directly north is in hanging wall, Blackstone shale in west flank Whiskey Creek anticline is foot wall.
14.2 to 16.1	The route traverses a belt of slice faults which repeat narrow plates of Colorado shales, Cardium and Blairmore sandstones; this belt is northern extension of Highwood uplift known better in area directly west of Turner Valley oil and gas field.
15.5	South — Trail leads ¼ mile to site of Iron Creek Elbow No. 1 well, drilled into Rundle at 5,582 feet, abandoned in 1938.
16.5	North — Prominent ridge across Elbow River is underlain by west-dipping Belly River sandstone; underlying Wapiabi shale is visible in exposures in river cut banks. These strata are in east flank of regional broad syncline with axial line fault of small displacement and minor superimposed folds.
17.2	Forestry Gate, Bow River District.
17.4	South — Branch road.
17.7	Camp ground.
18.1	North — Prominent ridge across river underlain by west-dipping Belly River strata located in hanging wall of minor strike fault.
18.8	North — Belly River sandstone exposed in river cut bank.
19.6	Wooden bridge crossing McLean Creek. Upper Colorado transition beds dip east in west limb of regional broad syncline. Camp site at west approach to bridge.
20.3	South — Road outcrop, Wapiabi shales and upper transition beds.
	North — Belly River sandstones exposed in prominent ridge dip east in west limb of regional syncline. Wapiabi at bridge conformably underlies Belly River sandstone.
20.4	Bridge crossing Elbow River. Wapiabi strata excellently exposed, dip east in middle limb; regional broad syncline on east, Moose Mountain dome on west. Picnic sites located at north approach to bridge.
20.6	Cattle guard and gate.
20.9	Elbow Ranger Station.
21.4	Gate.
22.5 to 25.4	Route west traverses belt 3 miles wide underlain by Blairmore strata dipping east in southeast limb of Moose Mountain dome.
22.9	South — At roadside is well site of Heron Petroleum No. 1, drilled in 1929 and 1930 to total depth of 3,590 feet, abandoned in Mississippian on east flank Moose Mountain dome.
23.7	North — Branch road leading to Moose Mountain Fire Lookout.
25.0	South — Blairmore sandstone exposed in canyon wall and on ridges located on southeast flank, Moose Mountain dome.
	North — Road outcrop, Blairmore sandstone and Cadomin conglomerate. Contact with underlying Kootenay formation is concealed.
25.1	North — Road outcrop, Kootenay sandstone, shale and coal seams.
25.2	East — Road outcrop, deformed Kootenay strata.

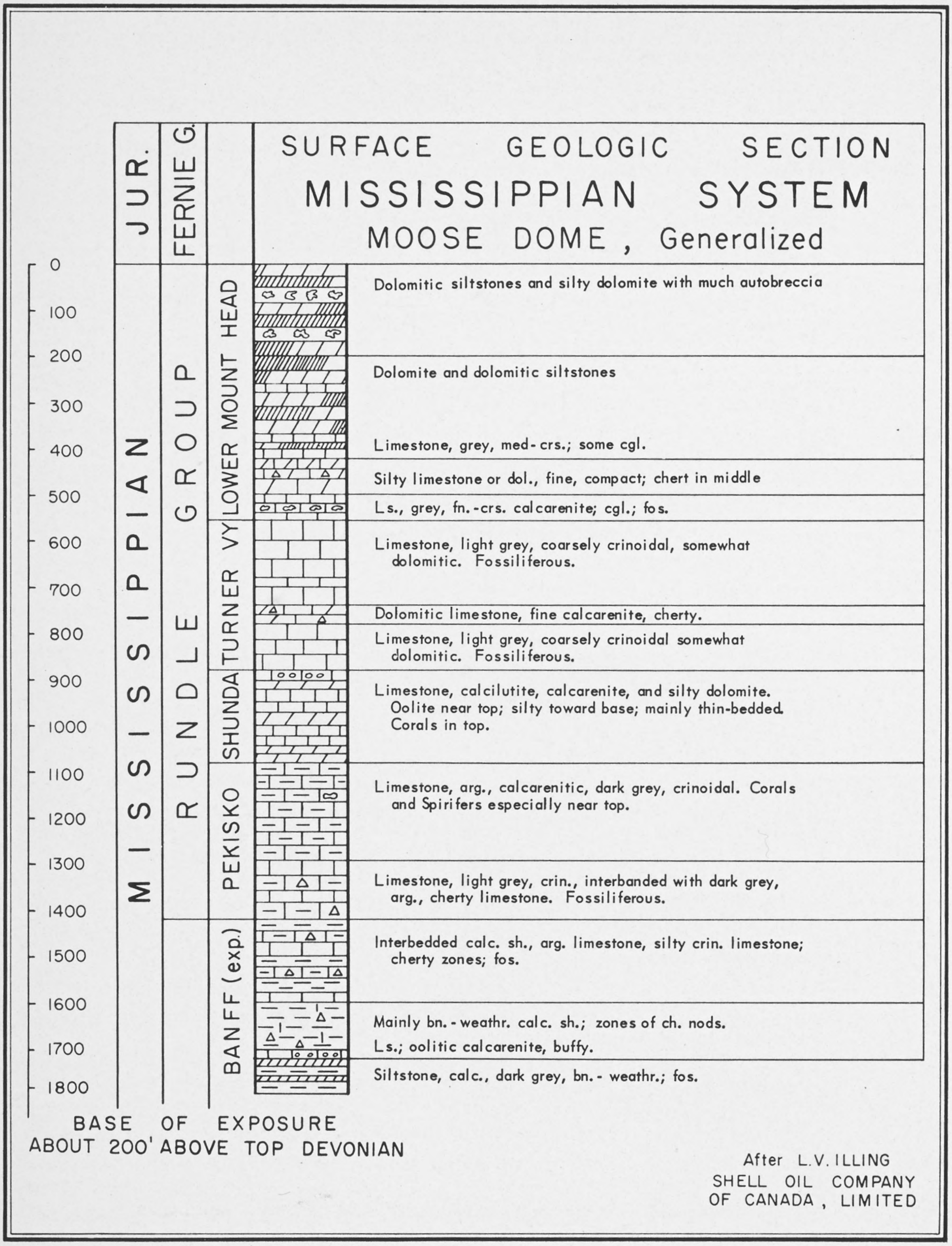


FIGURE 16

Mississippian section at Canyon Creek, miles 1.7 to 3.6, Road Log No. 2A.

25.3 Wooden bridge crossing Canyon Creek. Kootenay strata exposed at approach and in banks of creek. (See Figs. 15 and 17). The creek heads in the Front Range and transects Powder Face Ridge and Moose Mountain dome, Palaeozoic inliers of the Inner Foothills belt.

25.5 North — Branch road, route of Road Log No. 2A, leads up Canyon Creek to core of Moose Mountain dome and sites of several wells drilled 1933 to 1946. Road reconstructed to service Calstan-Shell Moose Mountain 16-6, Lsd. 16, Sec. 6, Twp. 23, Rge. 6, W5M. spudded in May, 1959. Rundle section well exposed on road and in Canyon Creek. (See Fig. 16).

25.6 South — Branch road leads to camp grounds located on north bank of Elbow River. Lower Blairmore and deformed Kootenay strata exposed in river channel. (See Figs. 15 and 18).

26.0 South — Carbonates of the Rundle group exposed in canyon below. Fernie, Kootenay and Blairmore on south plunging axis of Moose Mountain dome form heights directly south.

27.0 Elbow Falls camp. Falls break over resistant Rundle carbonates which dip west in middle limb of Moose Mountain dome on east, narrow secondary syncline on west. (See Fig. 19).

27.3 Gate.

27.4 Wooden bridge crossing Prairie Creek, Rundle exposed in channel. Headwater channels of creek occur at mile 5.5 of Road Log. No. 3.

27.5 South — Rundle strata with opposed dips form limbs of secondary anticline, steep limb on east, plunge is southeast. Fernie-Kootenay sequence weather brown in exposures on west limb directly in foot wall of Prairie Mountain thrust fault, a back-limb fault. Rundle carbonates in hanging wall exposed on skyline directly west; truncation of beds along fault is apparent. (See Fig. 20).

27.7 North — Rundle carbonates exposed in hanging wall of back-limb fault in west flank of Moose Mountain dome.

27.8 South — Beaver dam below road.

28.2 Forestry gate. Branch road leads to camp ground.

28.6 Roadside outcrop, Rundle carbonates dipping west in Prairie Mountain back-limb fault plate.

29.1 Culvert.

29.2 North — Road outcrop, Kootenay sandstone.

29.5 North — Branch road.

29.7 to 31.1 Road outcrop, Blairmore strata dipping west in Prairie Mountain back-limb fault plate.

31.1 West — Scarp face of Rundle carbonate located in west limb of Forgetmenot anticline, a Foothill Palaeozoic inlier; fore-limb of fold is removed by subsidiary faults and erosion; locally the Rundle overrides fault slices of Fernie, Kootenay, Blairmore and Colorado strata. Major thrust fault underlying anticline is continuous southward with Dyson Mountain thrust; surface trace of thrust swings abruptly eastward a few miles south of here and defines the north and east perimeter of Dyson Mountain syncline located in Dyson Creek map-area. (See Figs. 3 and 4 in paper by Dahlstrom and Henderson, this book.)

31.2 West — Good view of Elbow River Gap cut in hanging wall block of Dyson Mountain thrust. Scarp south of Elbow River is called Forgetmenot Ridge; north of river, Powder Face Ridge. Front Range is visible through Gap. (See Fig. 21).

32.0 South — Camp ground.

32.8 Approximate position of surface trace of Dyson Mountain thrust fault, Powder Face and Forgetmenot Ridges in hanging wall. For structural extension northward see notation mile 15.0 to 15.4, Road Log No. 3.

33.5 to 34.0 Road outcrop, Rundle carbonate dipping west in west limb of Forgetmenot anticline.

34.0 West — Confluence of Elbow and Little Elbow Rivers; Front Range in middle ground.

34.2 Road junction, continue southwest up Little Elbow River; this is a Forestry fire road, public access generally not permitted. **Route north, Road Log No. 3,** leads around west flank and north plunging end of Moose Mountain dome and joins with Trans-Canada Highway at mile 19.1 of Road Log. 1.

FIGURE 17 — Kootenay sandstone and shales, Canyon Creek, Mile 25.3 Road Log No. 2. Photograph by J. C. Mawdsley.

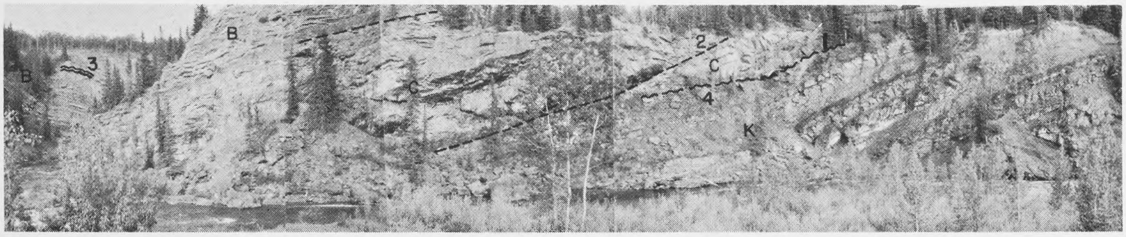


FIGURE 18 — Lower Blairmore-Kootenay section in southeast flank of Moose Mt. dome on Elbow River, Mile 25.6, Road Log No. 2. Unconformity (1), bedding plane thrust fault (2), **Metacypris persulcata** zone (3), **Ptilophyllum** sp. zone (4), Blairmore (B), Cadomin (C), Kootenay (K). Photograph by P. M. McGill.

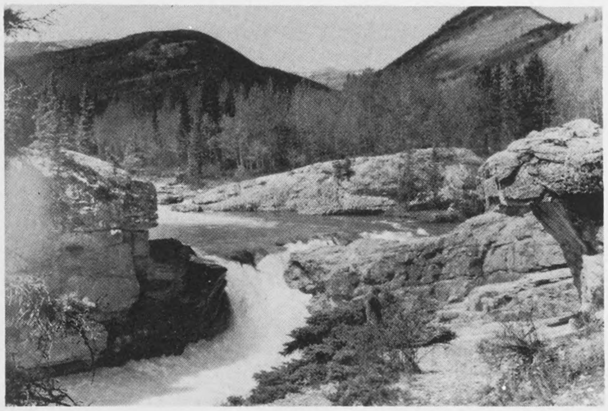


FIGURE 19 — Elbow Falls, breaking over Rundle strata in west flank of Moose Mountain dome, mile 27.0, Road Log No. 2. Photograph by J. C. Mawdsley.

June 12, 1966.

FIGURE 20 — Rundle strata in hanging wall of Prairie Mountain thrust forms cliff on right, Rundle with overlying Kootenay and Fernie strata in foot wall in central and left parts of picture; mile 27.5 to 28.6, Road Log No. 2. Photograph by J. C. Mawdsley.

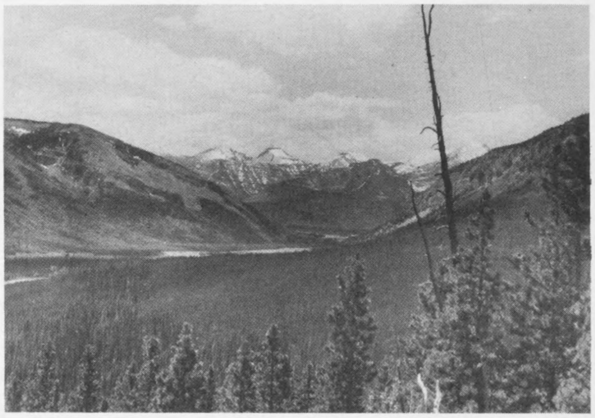


FIGURE 21 — Elbow River Gap cut in Rundle strata in hanging wall of Dyson Mountain thrust. Forgetmenot Ridge south of Gap; Powderface Ridge north of Gap; first Front Range in hanging wall of McConnell thrust in background; mile 31.1, Road Log No. 2. Photograph by J. C. Mawdsley.

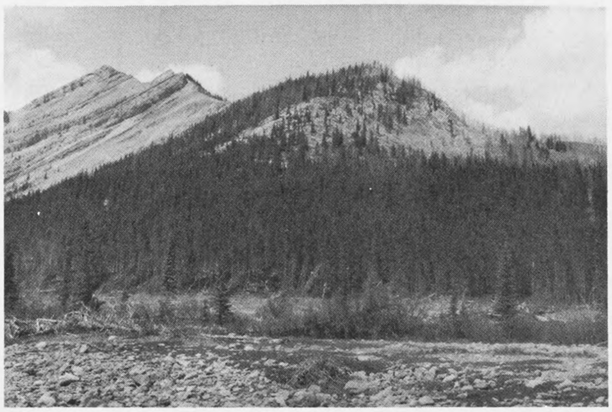


FIGURE 22 — East limb of Nahahi syncline, first Front Range, in hanging wall of McConnell fault, directly north of Little Elbow River; mile 36.8 to 37.2, Road Log No. 2. Rundle and Banff strata in peaks on left, Palliser in centre, all in hanging wall, Belly River strata in foot wall underlying slopes on right. Photograph by J. C. Mawdsley.

34.2 to 47.5 Route leads westward through a major syncline and anticline located in the thrust plate of the first Front Range, thence southward along the Mesozoic valley between first Front Range (north end of Highwood Range) and the second Front Range (Misty Range).

34.3 Bridge crossing Ford Creek.

35.2 South — Confluence of Little Elbow River (from the west) and Elbow River (from the south).

35.2 South — Outcrop in banks of Little Elbow River. Upper Blairmore sandstones dip 50 degrees westward in west flank of regional Powder Face-Forgetmenot Ridges anticline. Contact of Blairmore with Blackstone is located directly upstream.

35.8 South — Tree-covered hogsback formed in Cardium sandstone, topographic saddle directly southwest is underlain by Wapiabi shale, succeeding tree-covered ridge is held up by Belly River sandstones.

36.1 West — Little Elbow River Gap cut in the easternmost Front Range (physiographically continuous southward with Highwood Range and Livingstone Range). Highest pyramid-shaped peak directly south of Gap is Mount Glasgow, peak framed in gap is Mount Remus, Mount Romulus is directly behind. The latter two mountains, cut in Palliser limestone, form the east and west limbs of a large anticline ('Fairholme anticline') traversed by this route at mile 40.2.

Northwest — Nahahi Ridge dominates skyline. Peaks on ridge formed in Rundle group, brown talus below on Banff formation, small exposures of resistant carbonate at base is Palliser. Nahahi Ridge forms the east limb of a regional frontal syncline located in the hanging wall of McConnell thrust. (See Fig. 22).

36.5 Road outcrop, Belly River sandstone in west flank of Powder Face-Forgetmenot Ridges anticline, located in foot wall of McConnell thrust.

36.8 South — Palliser carbonates form scarp directly in hanging wall of McConnell thrust. Wapiabi shales exposed at base occur in small fault slice intervening Belly River sandstones and Palliser carbonates. (For north view, see Fig. 22). The McConnell fault zone can be traced structurally and by physiographic expressions along this lineament for over 250 miles northward to and beyond the Athabasca River, and southward to the Highwood River.

36.9 to 37.0 Road outcrop, Palliser carbonates dip west in east limb of frontal syncline.

37.2 Northwest — Profile of Nahahi Ridge. Palliser carbonates on east, brown shaly limestone of Banff formation above. Rundle carbonates in peak or skyline; strata dip west in east limb of regional frontal syncline.

37.4 Road outcrop, Banff formation.

37.8 South — Lower Rundle carbonates form bluff in river channel.

38.0 Ford crossing Nahahi Creek, Rundle carbonates exposed in channel.

38.3 South — Basal Rundle carbonates dipping gently west.

38.5 Bridge crossing Little Elbow River. Basal Rundle flat-lying in trough of frontal syncline. Gentle east dips of west limb of syncline visible in exposures across the river.

38.6 South — Scarp formed in Rundle carbonates; strata dip east in middle limb, syncline on the east, anticline in the west.

38.7 North — Shoulder Creek joins Little Elbow River below road, 'Middle Banff' limestone exposed in channel.

39.2 to 40.0 South — Road outcrop, Palliser formation.

40.2 Parking area. At this locality the Little Elbow River transects the core of 'Fairholme' anticline; Cambrian strata are exposed in river channel, Fairholme beds are poorly exposed in wooded lower slopes; scarp forming Palliser strata in the east and west limb of the anticline respectively form Mount Remus and Mount Romulus seen directly north.

40.3 South — Road outcrop, conglomerate; Recent, Pleistocene or Cambrian? From a superficial examination, what is your theory?

40.4 to 41.0 South — Road outcrop, Cambrian limestone.

40.5 North — Channel outcrop, Cambrian limestones.

41.1 North — Anticlinal flexure in basal Fairholme strata located in west limb of major anticline.

41.5 West — Misty Range, second Front Range at this latitude. The western Palaeozoic fault slice of this Range is the south structural continuation of Rundle Range of Banff area. The range plunges under Mesozoic valley 18 miles southeast. Peaks in foreground formed in Rundle group; Banff formation at base is thrust on Jura-Triassic strata.

41.7 to 41.9 North — Road outcrop, Fairholme beds.

42.6 North — Structural convergence, drags, and faults apparent in Fairholme-Palliser sequence in south face of Mount Romulus.

42.7 Bridge crossing creek, Fairholme strata exposed in channel.

43.6 Road outcrop, Palliser strata dipping steeply west in west limb of major anticline.

43.8 North — Profile view of Mount Romulus showing Rundle to Fairholme sequence, forming west limb of anticline. Fisher Peak (10,015 feet) is 2 miles northwest of Mount Romulus.

43.9 Culvert. Exshaw formation exposed directly north.

44.2 East — Outcrop of Rundle with good intermediate porosity.

44.4 Stream crossing. Mississippian exposures in gully.

44.7 West — Peaks in Misty Range formed in reddish beds of Rocky Mountain group and grey beds of Rundle group.

44.8 Northeast — View of Mounts Romulus and Remus, Palliser peaks in opposite limbs of major anticline, anticlinal core traversed at mile 40.2.

45.0 Stream crossing. Mississippian argillaceous carbonates exposed at roadside.

46.3 Northwest — Complex structure in Misty Range thrust block. Palliser riding on upper fault is thrust over Rundle, which is overthrust onto Triassic Spray River and Rundle sequence of the west flank of regional anticline.

47.5 West — Tombstone Mountain, Misty Range. Palliser thrust over Kootenay formation.

East — Forestry's rain collector in alpine meadow. This is the headwater divide between the Little Elbow and Elbow Rivers. The road continues southward and thence eastward along the north branch of Sheep River and terminates in the town of Turner Valley. Poor fords crossing streams in the Front Ranges make the road impassable to automobiles.

ROAD LOG NO. 2A: CANYON CREEK TO CULMINATION OF MOOSE MOUNTAIN DOME

The route leads north four miles along Canyon Creek to sites of several early wells drilled on the axis and approximate culmination of Moose Mountain dome. Grand exposures of the Rundle sequence are located along the road and creek. (See Fig. 16). An aerial oblique view of the Canyon Creek Valley is provided in the photograph accompanying paper by Dahlstrom and Henderson, and an expansive photograph of the box-canyon wall showing Rundle stratigraphy accompanies paper by Illing, this book.

Mile:

0.0 Junction, route leads north along Canyon Creek to confluence with Moose Dome Creek. Junction is mile 25.5 of Road Log No. 2.

0.1 to 0.8 East — Conglomerates at base of Blairmore formation exposed in two ledges in hillside, Kootenay sandstone exposed in wall of Canyon Creek, route located on Fernie shale; all strata dip east in east flank of Moose Mountain dome.

0.8 East — Basal Kootenay sandstone, apparently with uppermost 'Passage Beds' at base.

1.5 West — Rundle carbonates in east limb of Moose Mountain dome, crops out in forested hillside.

1.7 to 2.2 East — Thick bedded, uppermost Rundle carbonates exposed in walls of creek and at roadside.

2.2 Route trends westward and traverses dip section of Rundle exposures. (See Fig. 16).

2.8 Gate — Danger of hydrogen sulphide from currently drilling Calstan-Shell Moose Mountain 16-6, Lsd. 16, Sec. 6, Twp. 23, Rge. 6, W5M. lying in lethal concentration in box-canyon, obey signs.

Ice Caves _ See map. The ice is not a remnant of the Ice Age
Cold drafts freeze the water seeping into the caves.

3.6 Rundle and upper Banff exposed in cliff directly south approximately at culmination of Moose Mountain dome. (See excellent photographs of this cliff accompanying papers by Dahlstrom and Henderson, and by Illing, in this book.)

3.7 Junction. Road north leads up Moose Dome Creek to Calstan-Shell Moose Mountain 16-6, Lsd. 16, Sec. 6, Twp. 23, Rge. 6, W5M. spudded May, 1959. Road west leads a short distance to several sites of abandoned Moose Mountain wells drilled in years 1933 to 1946. The deepest of these wells, Int. Oil and Gas Elbow Falls 2A drilled to total depth of 3,158 feet and encountered a flow of over 3,500 Mcf. of gas from Cambrian strata, abandoned 1946.

ROAD LOG NO. 3: A TRAVERSE OF THE FOOTHILLS ALONG JUMPINGPOUND CREEK

The route of Road Log No. 3 trends northward on strike of the "Mesozoics" on the Prairie Mountain thrust plate directly east of the Front Range. The route then trends northeast and east along Jumpingpound Creek to cross the north plunging axis of Moose Mountain dome and the imbricated fault slices of the Outer Foothills. Whereas rock exposures on the route are generally poor, fine Cardium and Cadomin sections do crop out. The route provides access to a pleasant, scenic drive.

Mile:

0.0 East — Road outcrop, Kootenay sandstone and coal seam deformed directly in hanging wall of small fault. The route northward for 18 miles is essentially along strike; Mesozoic sequence, Fernie to basal Belly River, dip homoclinally on west limb of Forgetmenot anticline, hanging wall structure of Dyson Mountain thrust.

West — Front Range frontal structure, Nahahi syncline, formed in Palliser to Rundle sequence thrust eastward on McConnell fault.

0.4 East — Road outcrop, Cadomin conglomerate and Kootenay sandstone.

West — Blairmore sandstone exposed in near cliff face.

1.3 West — Front Range scarp designated Nahahi Ridge, forms east limb of frontal syncline. Rundle on skyline, brown talus slope overlies Banff, Palliser at base is directly in hanging wall of McConnell fault.

1.5 to 2.0 Road outcrop, Blairmore sandstone; Blackstone shales underlie strike valley directly west.

2.1 Northwest — Tight frontal syncline apparent in Rundle carbonates in Compression Ridge.

2.5 East — Road outcrops, Blackstone shale.
West — Tree covered ridges in foreground held up by Cardium formation.

3.3 Drainage divide, Ford Creek flows south to Elbow River, Trail Creek flows north to Prairie Creek.

3.5 Road outcrop, Blackstone shale.

4.5 West — Scarp face of Nahahi Ridge in the Front Range, with complex drag folds in "Palaeozoics."

4.7 to 5.4 West — Road outcrop, Blackstone shale.

4.8 Culvert crossing Trail Creek.

5.5 Bridge crossing Prairie Creek, creek enters Elbow River at Mile 27.4, Road Log No. 2.

West — East limb of frontal syncline visible in Compression Ridge.

East — Rundle carbonates exposed on back slope of Powder Face Ridge and Blairmore strata exposed directly downstream from bridge are in west limb of Forgetmenot anticline.

5.7 Burnt area, new growth recently established.

6.1 East — Road outcrop, Cardium sandstone.

6.5 to 7.1 East — Road outcrop, Wapiabi shales.

6.6 West — Compression Ridge, structurally continuous with Nahahi Ridge, partially separated by transverse near vertical fault.

7.5 East — View downstream along tributary and trunk channel of Canyon Creek. Creek transects Palaeozoic in core of Forgetmenot anticline in middle ground, and of Moose Mountain dome in background.

7.6 to 7.7	East — Roadside outcrop, Cardium formation.
8.8	Bridge crossing Canyon Creek. Cardium formation exposed at northwest approach and upstream; camp ground at northeast approach.
	West — Compression Ridge located directly south of creek; Mount Bryant, directly north of creek; succeeding syncline and anticline visible in east slope of these mountains.
8.9	Bridge crossing tributary of Canyon Creek.
9.0	Northeast — Blairmore sandstone exposed in valley wall.
9.5	West — Canyon Creek tributary cut in Blackstone shale.
10.0	Northwest — Most mountain peaks and slopes eroded in Palliser massive carbonates.
11.2	Boundary of Elbow and Jumpingpound Districts of Bow River Forest, Rocky Mountain Forest Reserve.
	East— Road outcrop, Cardium, lower sandstone and conglomerate, medial shale, and upper sandstone.
11.3 to 11.9	East — Scattered road outcrop, Upper Cardium sandstone and basal Wapiabi shale.
12.2 to 12.9	Road outcrop, Cardium sandstone.
12.9 to 13.1	Road outcrop, Blackstone shale.
13.4	Wooden bridge.
13.7	Roadside talus; Blairmore sandstone and conglomerate crop out in Jumpingpound Creek.
13.8 to 14.0	West — Blairmore sandstone exposed in cut bank, Jumpingpound Creek.
14.7	Bridge crossing Jumpingpound Creek.
14.9	South — Cadomin conglomerate exposed in creek.
15.0	Bridge crossing Lusk Creek. Route leads northeast and traverses the Inner and Outer Foothills belt.
15.0 to 15.4	Road outcrop, deformed Kootenay sandstone and shale directly in hanging wall of subsidiary fault imbric to Dyson Mountain thrust. Anticline weakly expressed here is northern extent of Forgetmenot anticline crossed at Mile 33.5 to 34.0 of Road Log No. 2.
15.4	North — Road outcrop, Cadomin conglomerate, Kootenay sandstone and shale located in hanging wall of Dyson Mountain thrust.
15.8	Creek outcrop, deformed sandstone and shale of Blairmore formation.
15.9	North — Cadomin conglomerate in ridge, located in hanging wall of slice fault.
16.0	Bridge crossing Jumpingpound Creek.
16.2	Road crosses Cadomin outcrop.
16.3	Bridge crossing Jumpingpound Creek.
	North — Cadomin exposed in ridge, located on west flank of anticline formed in north part of Prairie Mountain back-limb thrust plate.
16.7	North — Road outcrop, Kootenay sandstone and shale.
17.1	Bridge.
17.5 to 18.0	Road outcrop, deformed Kootenay grey sandstone.
17.7	South — Chevron folds formed in Kootenay strata.
18.0	Road outcrop, east-dipping Cadomin located in east limb of anticline formed in north part of Prairie Mountain back-limb thrust plate.
18.4	North — Road outcrop, Cadomin conglomerate overlying Kootenay sandstone directly in hanging wall of Prairie Mountain back-limb fault, axial line of the major anticline of Moose Mountain dome is directly east.
20.8 to 20.9	North — Road outcrop, Blackstone shale exposed in slice fault plate on northeast flank of Moose Mountain dome. Camp ground in meadow below road.
20.9	Forestry gate.

21.2	Meadow underlain by Wapiabi shale; Cardium folded anticlinally in tree-covered ridge, northeast, forms minor flexure in northeast flank of Moose Mountain dome.
21.3	Bridge crossing Sibbald Creek.
21.5	North — Branch road leads westward about 9 miles to the Kananaskis road.
22.5	Sibbald Flat underlain by Wapiabi shale.
23.7	Bridge crossing Bateman Creek. Approximate position, surface trace of small fault thrusting Wapiabi over Belly River. Belly River sandstone exposed upstream dipping nearly vertically.
23.8	North — Road outcrop, Belly River sandstone.
24.4	South — Moose Creek Trail.
24.5	North — Road outcrop, Belly River sandstone.
28.1	Forestry gate.
28.2	North — Jumpingpound Ranger Station.
28.3	Forestry gate.
28.9	Forestry gate, east boundary of Jumpingpound district.
31.0	Gates, flat underlain by Belly River formation, possibly in part basal Edmonton equivalents.
31.2	Texas gate.
31.7	Texas gate, Barnes ridge on north, Logan ridge on south; ridges located in hanging wall of small strike fault repeating Belly River sandstone at surface.
32.2	Texas gate, Belly River sandstone exposed in west slope of ridge directly north.
33.9	Texas gate. Route crosses belt of closely spaced fault slices which repeat successively parts of the Belly River-Colorado sequence.
34.4 to 34.6	East — Norman Lake.
35.8	Bridge crossing Little Jumpingpound Creek.
38.2	Junction with Trans-Canada Highway; this is Mile 19.1 of Road Log No. 1.

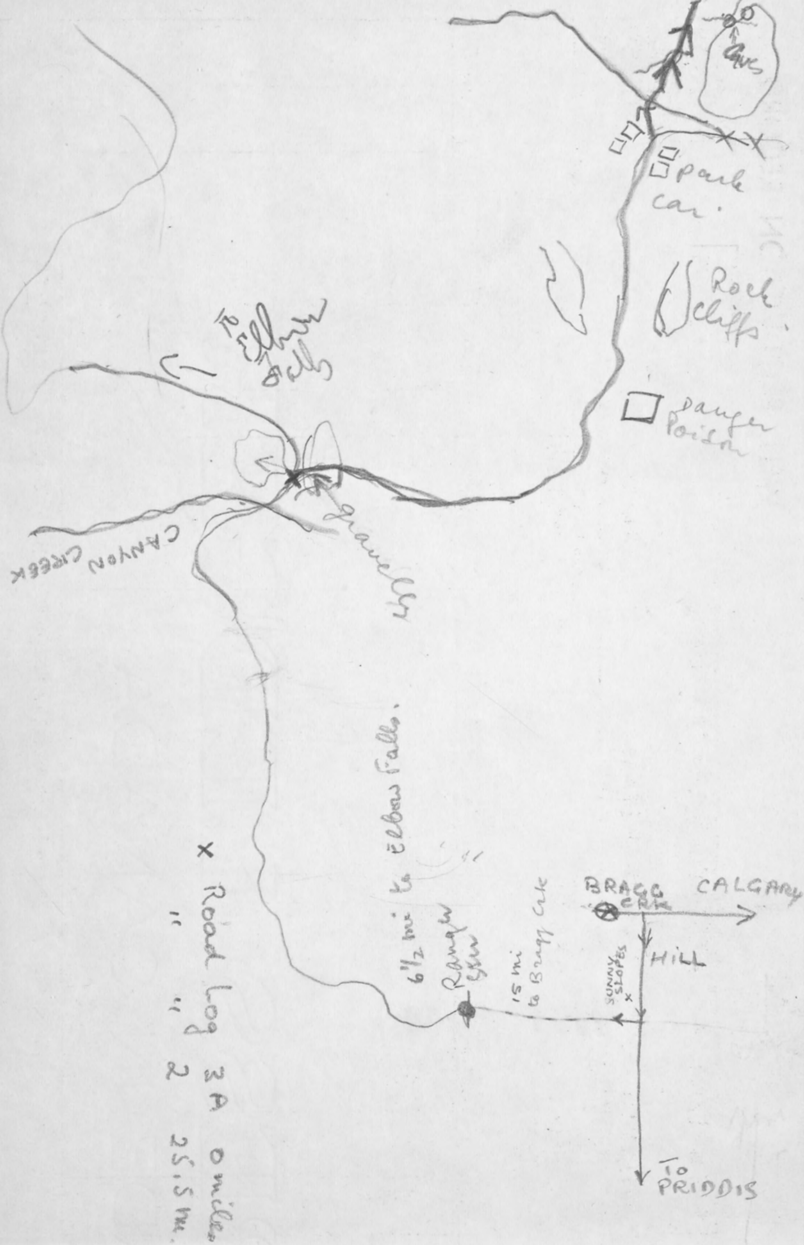
END OF ROAD LOGS

$5,00.

to be the first youth hostel in North America.

"Cathy had an old Ford car called Lovable and we'd drive out to Bragg Creek and stay at Wake-siah Lodge. I think

my last year at school. I'm not an outstanding teacher, but I have persisted in teaching conservation and love of the outdoors. Now at last it looks like something is being accomplished in this direction."


caves
park car.
Rock cliffs
Danger Poison
Elbow Falls
gravelly
CANYON CREEK
6 1/2 mi to Elbow Falls.
Ranger Stn
15 mi to Bragg Crk
SUNNY SLOPES
BRAGG CRK
CALGARY
HILL
TO PRIDDIS
Road Log 3A 0 miles
" " 2 25.5 mi.

WELL PRODUCTION RECORD

WELL: TOL ET AL CROSSFIELD 14*31*30*3

YEAR: 1965

C/F: F SEQ. NO.: 1333 2

D/P: | LS: 14 | SEC.: 31 | TWP.: 30 | RGE: 3 | M: 5

FIELD: CROSSFIELD

POOL: CUJA

ON PROD.: MO. 10 | YR. 60

FORWARD / TO DATE

OIL TOTALS: 61112

GAS TOTALS: 58854

WATER TOTALS:

MO.	OIL - BARRELS	GAS - MCF	WATER - BARRELS		GAS CREDITS	WATER CREDITS		ALLOWABLE
1	1249	2342					Flashlight Boots - 1	
2	1203	1856						
3	939	2021						
4	602	1551						

OIL AND GAS CONSERVATION BOARD - CALGARY, ALBERTA

Miss Mary Barclay was honored at the weekend when about 60 friends, ranging from pre-schoolers to grandparents, gathered at the home of Dr. and Mrs. Gerald Hankins. It was a tribute to the help she had given over the years in promoting conservation and a love for the outdoors. She is shown here being presented with an Annora Brown painting by Mr. Sidney Vallance. She also received a walking cane carved by Lawrence Grassi of Canmore who shares Miss Barclay's love of the mountains. Miss Jean MacAskill wrote a poem of tribute and children gave her a tin of imported cookies. — Randy Hill Photo

Albertan · June 8, 1966.

Page 185 at 2.4 mile Moose Mtn Drumheller Field Trip.

She taught kids nature's secrets

By LINDA CURTIS
Women's Editor

"Once a child learns to love a stone, he'll never throw it through a window."

This is the philosophy of Miss Mary Barclay, Grade 4 teacher at Stanley Jones School.

She was looking back over more than 40 years of teaching this week as she prepared to leave the classroom forever.

On the second floor of the school, with a bright southern exposure, it is no ordinary classroom. It is filled with children, tropical fish, tadpoles, dinosaur bones, fossils, rocks, frogs, lizards, stuffed gophers and large looseleaf binders filled with pressed plants gathered throughout Alberta.

Mary Barclay is a nature lover.

"For the last 20 years I've been working to give people what they don't want . . . an appreciation of the outdoors," she smiled sadly. "I've tried to arouse this love for nature in my students by taking them on field trips where they can discover its wonders for themselves.

"Never a trip goes by that some child doesn't bring me a wild rose or a bluebell and ask me what it is. These are flowers indigenous to Alberta. You would think every child would recognize them."

Miss Barclay has found the field trips provide a new avenue of communication between herself and her students. "We are different people out of the classroom," she explained.

"I have found that the children generally improve their grades, in every subject, when they take part in these field trips. They begin to look around . . . to find things out for themselves.

"But it's a sad truth that children these days lack imagination. I feel TV is largely to blame. We have provided them with instant entertainment. Everything is handed to them. We've robbed them of the most precious ingredients of childhood . . . curiosity and imagination."

Mary Barclay has an inquiring nature. Her love for the outdoors goes back as far as she can remember and prompted her to extend her education.

"I would go on hikes and trail rides and not know what was at my feet," she explained. "I decided I just had to know all about the flowers and the trees and the rocks. So I took time off from teaching to take courses in botany and geology. They have given me an even greater appreciation of the wonders of nature."

Mary's memory wandered back to her early days of teaching in Calgary. For relaxation she loved to hike and ride in the Bragg Creek area.

Along with her sister, Catherine, Dorothy Allen (now Mrs. Leon Simonetti) and Ivy Devereux, all teachers, she established what is believed to be the first youth hostel in North America.

"Cathy had an old Ford car called Lovable and we'd drive out to Bragg Creek and stay at Wake-siah Lodge. I think it's still standing. Then one 24th of May I got the idea of pitching a tent in the yard at the lodge. A fee of 50 cents a year was agreed upon.

"I could foresee a whole chain of these being set up and Ivy and Dorothy fell for the idea.

"We got so enthused, we rented a 9 x 12 ft. tent, pitched it at Bragg Creek on the July 1st weekend and that was the first hostel."

The tent was embellished with orange crates and straw mattresses, old pots and pans and the girls built a table of poles. They rented horses from Jake Fullerton and had wonderful weekends in the wilds.

"We eventually bought our own tent, put a floor in it and some walls and finally by 1936 it had grown into a real building. At first just the girls were in the group, but Joe Clitheroe came along and he was handy at fixing and building things, so he joined us.

"That first building was still at Bragg Creek until recently. It was donated to the Glenbow Foundation, so I'm not sure where it is now."

From that small beginning, hostelling grew in Canada. There are now almost 1,000 members in Alberta, one of the most active regions. Each year groups from the U.S. and other parts of the world see Alberta by hostelling.

"We used to hike from Morley to Banff," recalled Miss Barclay. "We blazed the trail that the Trans-Canada highway now follows. We often used to ride under the stars. You're never the same after such a ride. It brings the wonder, the love and the reverence for nature that our children lack today.

"Take away the spiritual and the intellectual from a human being and all you have left is the animal. That's what our society is doing.

"I see Ontario is spending several million dollars on outdoors education and the Alberta Teachers' Association is holding outdoor seminars that are wonderful. I am grateful to see this all happening in my last year at school. I'm not an outstanding teacher, but I have persisted in teaching conservation and love of the outdoors. Now at last it looks like something is being accomplished in this direction."

es

astrate,

e city

Also awaited today was an announcement by the electoral commission, named by the military regime to arrange for the election Sept. 11 of a constituent assembly to draft a constitution.

In Saigon moderate Buddhist leaders Tuesday gained control of the anti-government drive and called for an end to street demonstrations and fiery suicides. Saigon Buddhists were informed by moderate leader Thich (Rev.) Tam Chau that the struggle against the regime of premier Nguyen Cao Ky was being "reorganized." He charged the generals ruling South Viet Nam were guilty of "treason" but called for "understanding between the army and the people."

The change in the Buddhist tactics in the capital averted a violent showdown with Ky and chief of state Nguyen Van Thieu.

nted

campus

Kennedy

cades and happily mobbed Kennedy and his wife Ethel.

A group of students lifted Kennedy onto their shoulders and New York's junior senator made an impromptu speech urging the students to use their education "to help those of your fellow citizens who suffer from discrimination because of race."

His remarks were greeted with wild cheering.

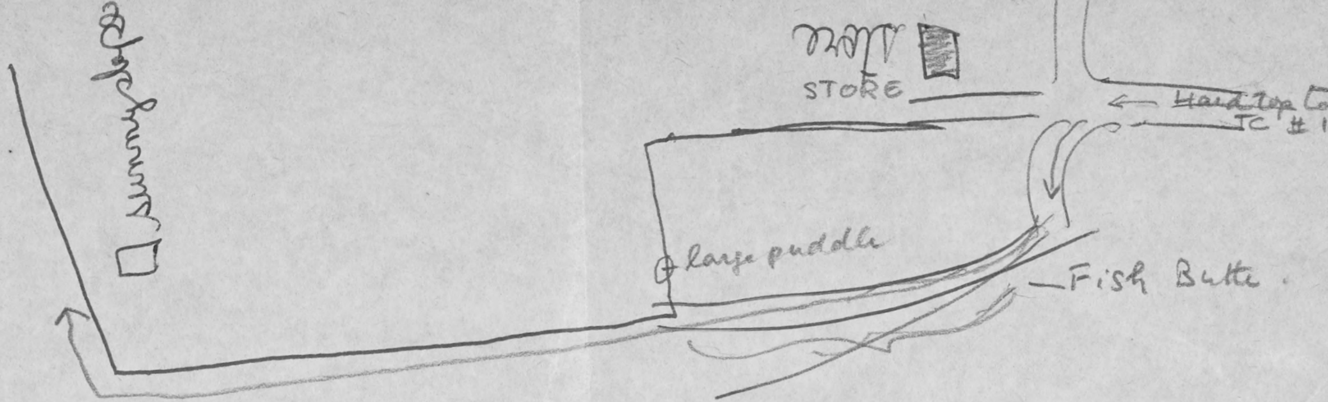
Kennedy later revealed he had been granted permission to visit the banned Nobel peace prize winner, ex-chief Albert Luthuli, who now lives under restriction 40 miles north of Durban.

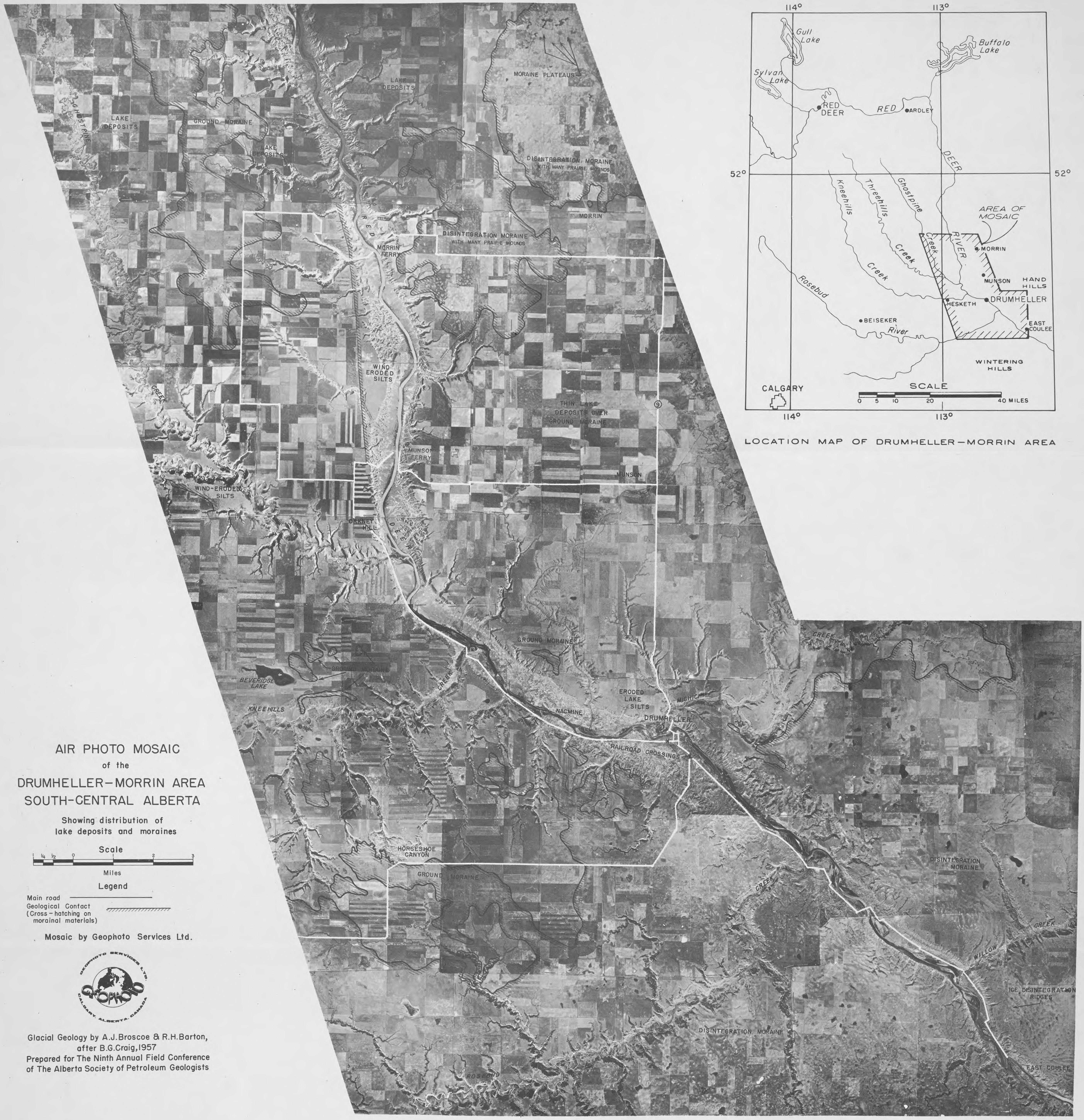
The permission was regarded as a major concession by the South African government and is about as close as the government has come to acknowledging Kennedy's visit.

Did MD break H

LONDON (CP) — A copy of Lord Moran's memoirs of his years as Sir Winston Churchill's doctor has been sent by the British Medical Association to the chairman of its central ethical committee, watchdog o doctors' ethics in Britain, it wa reported Tuesday.

A spokesman for the BMA de clined to confirm or deny new paper reports that the book ha


sunnyslope
STORE
large puddle
Fish Butte
Hard Top Co
JC #1



LOCATION MAP OF DRUMHELLER—MORRIN AREA

AIR PHOTO MOSAIC
of the
DRUMHELLER—MORRIN AREA
SOUTH-CENTRAL ALBERTA

Showing distribution of lake deposits and moraines

Scale

1 1/4 1/2 0 1 2 3

Miles

Legend

Main road

Geological Contact (Cross-hatching on morainal materials)

Mosaic by Geophoto Services Ltd.

GEOPHOTO SERVICES LTD. CALGARY, ALBERTA, CANADA

Glacial Geology by A.J.Broscoe & R.H.Barton, after B.G.Craig, 1957

Prepared for The Ninth Annual Field Conference of The Alberta Society of Petroleum Geologists

FIGURE I

GEOLOGY OF THE WESTERN FRONT RANGES
SOUTH OF THE BOW RIVER
ALBERTA

By John L. Usher

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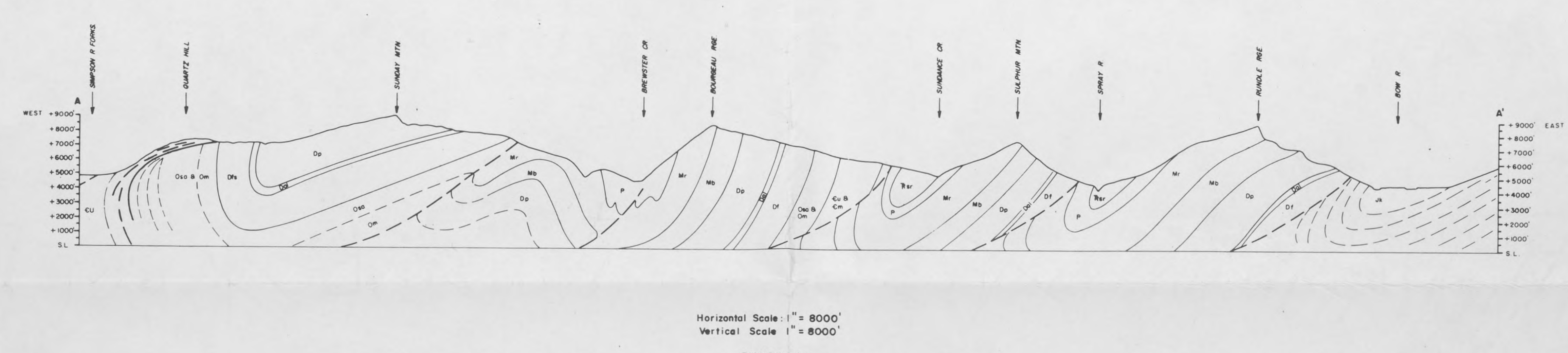
A.S.P.G. NINTH ANNUAL FIELD CONFERENCE

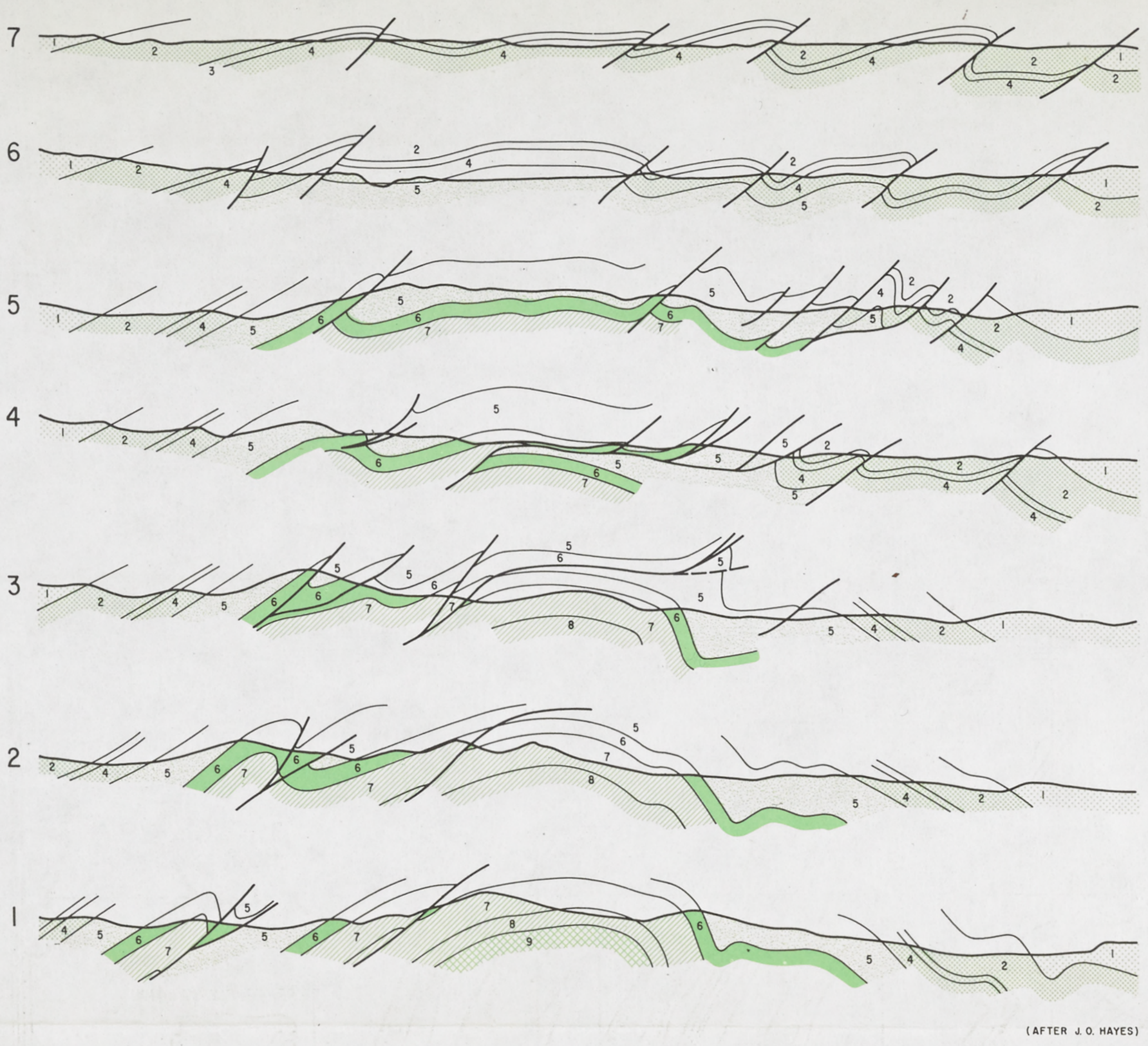


Horizontal Scale: 1" = 8000'
Vertical Scale 1" = 8000'

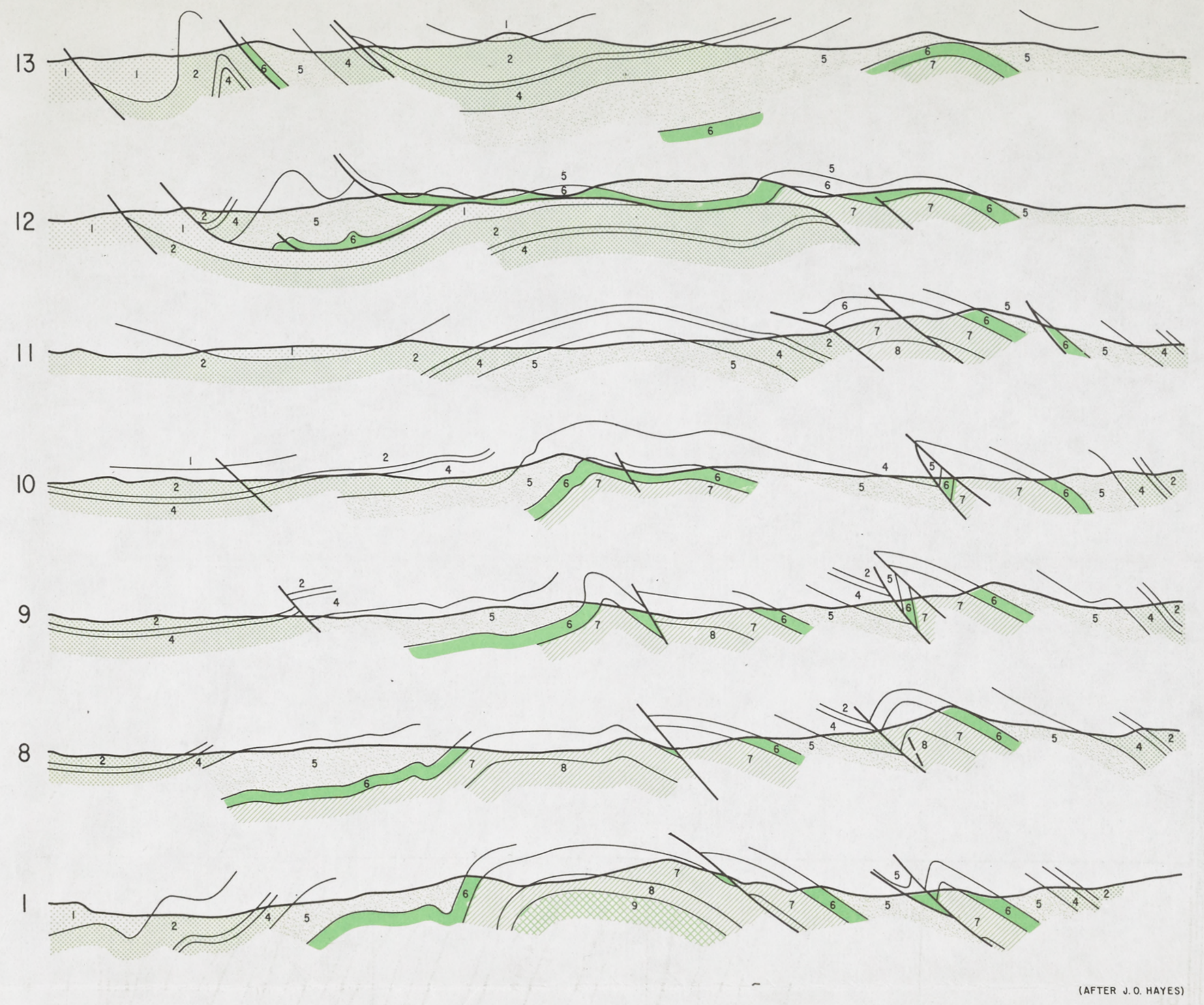
FIGURE Ia

GEOLOGIC CROSS SECTION A-A'

Levi Hoogerheide
2403 - 2 St. SW -
Calgary, Alberta



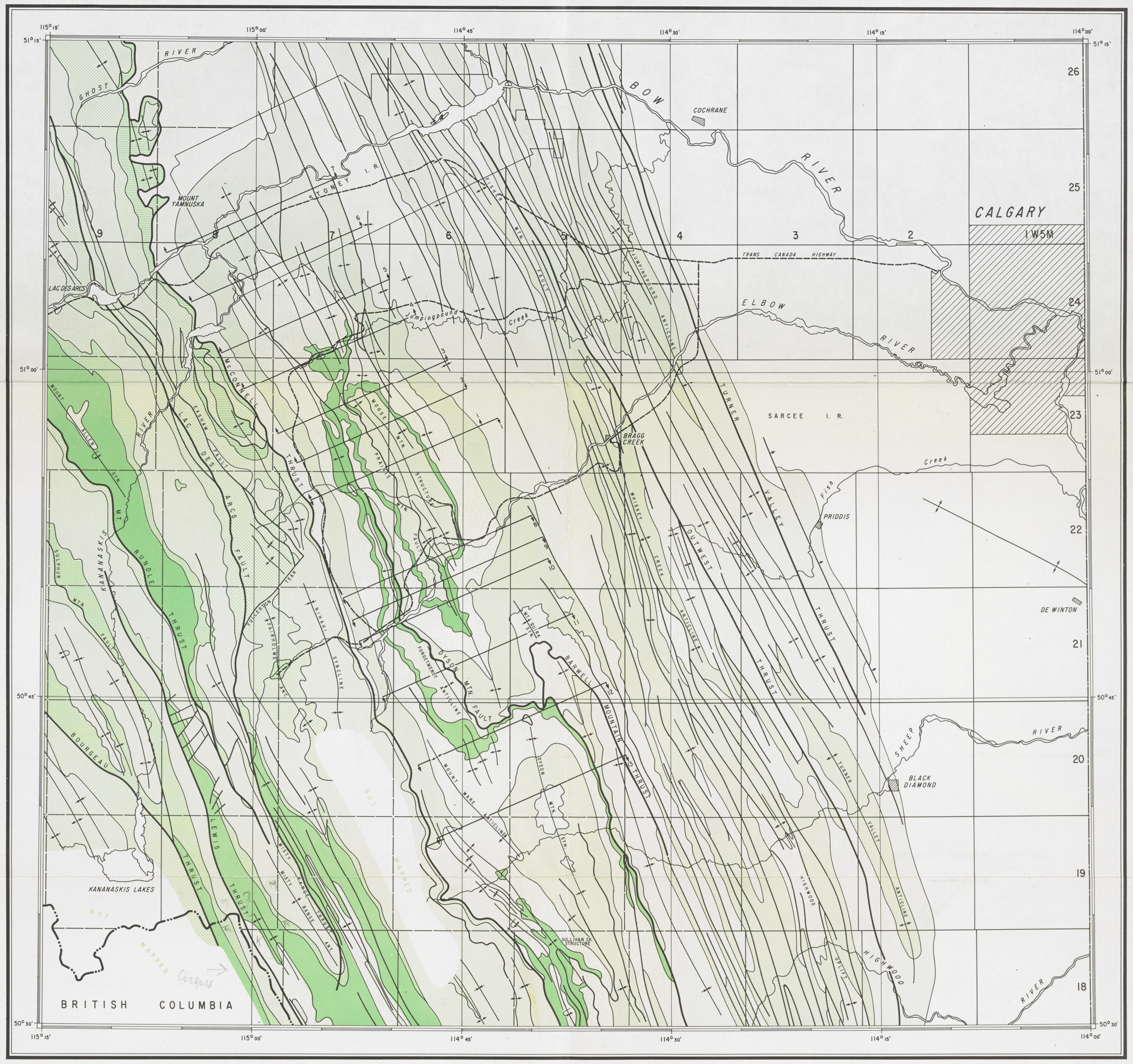
CROSS - SECTIONS THROUGH THE NORTHERN PART OF THE MOOSE MOUNTAIN STRUCTURE
- LOOKING NORTH -



CROSS - SECTIONS THROUGH THE SOUTHERN PART OF THE MOOSE MOUNTAIN STRUCTURE
AND THE DYSON MOUNTAIN SYNCLINE - LOOKING SOUTH

SCALE IN MILES

1 BELLY RIVER | 2 WAPIABI | 3 CARDIUM | 4 BLACKSTONE | 5 BLAIRMORE | 6 JURASSIC | 7 RUNDLE | 8 BANFF | 9 PALLISER



GEOLOGICAL MAP
MOOSE MOUNTAIN AREA

COMPILATION BY G. G. L. HENDERSON

TO ACCOMPANY A PAPER ON THE "MOOSE MOUNTAIN AREA"
BY C. D. A. DAHLSTROM AND G. G. L. HENDERSON
IN THE 1959 ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS FIELD CONFERENCE GUIDE BOOK

DRAFTING BY W. E. DICKSON

Scale : 1 inch to 4 miles

LEGEND

- TERTIARY
- UPPER CRETACEOUS (BELLY RIVER & YOUNGER)
- UPPER CRETACEOUS (PRE-BELLY RIVER)
- LOWER CRETACEOUS
- JURASSIC
- TRIASSIC
- MISSISSIPPIAN AND PERMO-PENN
- DEVONIAN
- CAMBRIAN

SYMBOLS

- MAJOR FAULTS
- OTHER FAULTS
  ALL FAULTS DIP WEST EXCEPT WHERE NOTED
- CONTACT
- ANTICLINE - UPRIGHT, OVERTURNED
- SYNCLINE - UPRIGHT, OVERTURNED
- LINE OF SECTION
- ROUTES FOR WHICH ROAD LOGS ARE AVAILABLE IN GUIDE BOOK